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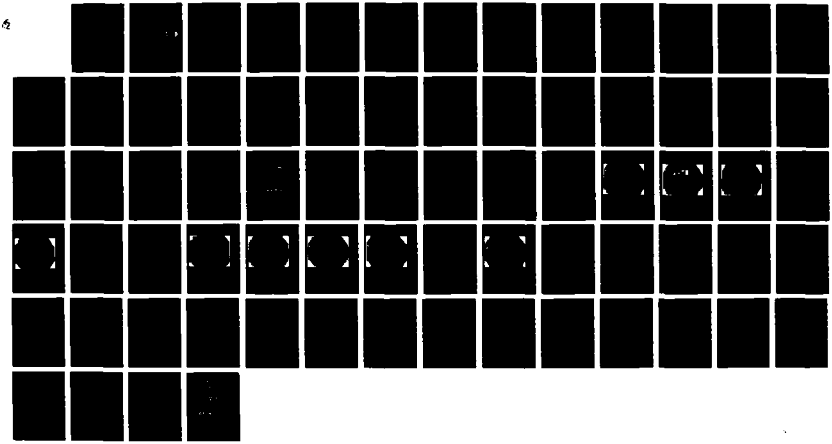

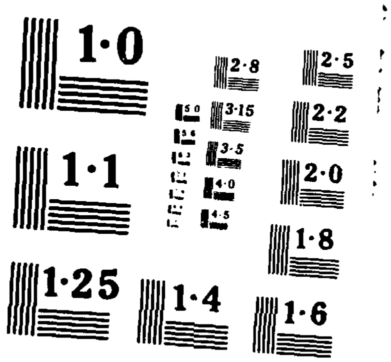
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A PERSONALIZED AND PRESCRIPTIVE DECISION AID FOR CHOICE FROM A DATABASE OF OPTIONS

Prepared by

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In many decision-making contexts there is a need for aids which cater flexibly to individual users in their preferred ways of organizing information and solving problems, but which guard against potential errors or biases inherent in common approaches to decision making. DSC has developed principles of personalized and prescriptive decision aiding which respond to this need, and which are based on experimental findings and theoretical models in cognitive psychology. In Phase I of this project, those principles were applied to the development of an aid for attack submarine approach and attack. In Phase II, the principles have been generalized and extended to the development of a generic personalized and prescriptive evaluation system. The system incorporates five basic cognitive interface modules to customize the user's interaction with the aid to provide prescriptive guidance, as well as a set of interactive dialogues or guides which blend all five functions in support of specific user-selected decision-making strategies. The aid has been tested and demonstrated in the context of a personnel selection application.

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1.0 INTRODUCTION

1.1 Objectives

The overall objective of this project has been to develop a prototype decision aid that successfully blends two features: (1) it is *personalized* in the sense that it accommodates individual differences in beliefs, values, preferred methods of problem structuring and analysis, preferred methods of organizing information and searching a database, and variations in cognitive "style," ranging from intuitive to analytical; and (2) it is *prescriptive* in the sense that it attempts in a variety of ways to steer users away from potential biases or errors commonly found in decision making and associated with preferred decision making strategies. During Phase I, a concept for such an aid was developed and demonstrated in the context of a submarine commander's decision as to when to launch an attack on an enemy target. This decision involves a difficult tradeoff between waiting to obtain a more accurate fire control solution, and increasing own vulnerability to enemy attack. The attack planning situation was rich enough to allow incorporation of a wide range of personalizing options selectable by individual users, as well as advisory prompts calling the user's attention to potential pitfalls or inconsistencies and alerting him to critical events. This demonstration prototype aid was described in the Phase I Technical Report (Cohen, et al., 1982).

The original objectives of Phase II were as follows:

(1) Complete computer implementation of the design concept developed in Phase I.

(2) Design, implement, and test enhancements of the original concept, by increasing the degree of personalization and the scope of the coverage of the advisory prompts.

(3) Design, implement, and test a general-purpose (non-testbed specific) personalized decision aid.

Early in Phase II it was decided, in conjunction with the ONR Scientific Officer, that the general-purpose personalized aid would take the form of a system for evaluating and selecting options from a large database. In order to stimulate potential commercial interest in the development of the concept, it was further decided that the database subject matter for initial application of the system should be a domain of widespread interest, and the problem domain of personnel selection (from a large database of applicant resumes) was chosen. The personalized aid itself, however, including the analytic model and interactive features, was to be generally applicable to any kind of option evaluation problem. Finally, in order to ensure that the general-purpose aid had the highest degree of personalization and prescriptive capability possible, it was decided to focus the effort involved in Objective (2) upon the general-purpose aid rather than the submarine attack planning aid. In this way, the end product would have the highest probability of being broadly applicable in a wide variety of decision-making domains.

1.2 Outline

This report provides, in Section 2.0, a background summary of the research literature describing the nature of commonly found cognitive biases in decision making, and the variations in problem-solving strategies characterizing different users, or indeed the same user at different times. It thus provides a rationale for the personalizing and prescriptive features. Section 3.0 describes the major differences between the attack planning and the personnel selection decision problems. Section 4.0 describes the general-purpose aid, highlighting the personalizing and prescriptive features. Section 5.0 describes a preliminary experimental test of the system, and Section 6.0 presents conclusions.

2.0 BACKGROUND

2.1 General Description of the Decision Process

The decision-making process can be conceptualized quite generally as consisting of a specific set of cognitive tasks (Figure 1). First, goals or objectives must be known or identified (if these are not present, there is no motivation to decide or act). Secondly, current circumstances, insofar as they are relevant to the achievement of a goal, are assessed. If a discrepancy is perceived between goals and reality, options for action are generated. If more than one option is available, a choice will be made.

This is by no means a rigid sequence: the process is usually iterative (for example, revising goals, reassessing the situation, or generating new options when the choice process fails to turn up an acceptable alternative); and steps may be skipped (when, for example, the appropriate action is known based on past experience with very similar situations). But the basic set of possibilities is as shown, at least in many of the decision contexts we have considered, and some such framework is critical, we believe, for identifying the specific aspects of human performance where personalized and prescriptive aiding may be of use.

It is convenient to break each of these major tasks down into more specialized cognitive subtasks. For example, situation assessment consists of collecting and viewing data or evidence, deriving inferences, developing some sense of confidence in the conclusions, and continuing, perhaps, to draw further higher-level inferences. Again, the steps may be iterative, may be combined, or may be skipped altogether by some decision makers in some situations.

(Note that the term "evidence" is quite relative; evidence in one process may be the highly uncertain conclusion of a prior analysis.)

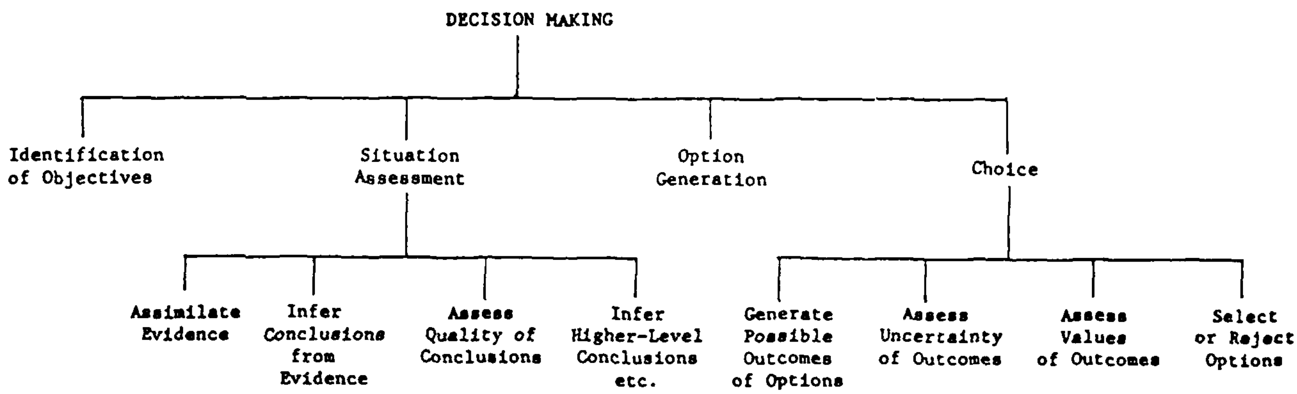


Figure 1: Potential Cognitive Subtasks in the Decision Making Process

2.2 Basis for Prescriptive Features

During the past 10-12 years a substantial amount of research has identified and quantified the types of cognitive biases or errors commonly made during the decision process. The prescriptive features of any aid must be designed to prevent or counteract these types of biases, to the extent possible.

Each of the cognitive subtasks identified in Figure 1 has been associated, at least in laboratory research, with characteristic shortcomings in reasoning. Thus, by placing recent findings in cognitive psychology within this framework, we may derive a tentative specification of the types of prescriptive features that would be most appropriate.

The following summary is not exhaustive; it is meant only to touch on some of the issues that bear on the present work. Three important themes, however, emerge: (1) Unaided decision processes employ simplifying heuristics that at best only approximate prescriptively accepted rules (e.g., Bayesian probability theory); (2) a typical effect of such heuristics is that awareness of uncertainty is suppressed; and (3) in many instances, biases are a result of (otherwise successful) efforts to utilize natural knowledge structures and processes of reasoning.

Assimilate Evidence. Patterns of information search in laboratory tasks tend to avoid stringent tests of favored hypotheses (Wason, 1960, 1981; Einhorn, 1980). At the same time, there is a tendency to seek *confirming* evidence of an already well-supported hypothesis, rather than take action or consider evidence that bears on other issues (Shaklee and Fischhoff, 1982).

Infer Conclusions. A number of studies, which show that a statistical *model* of a person's judgment process can outperform (in accuracy) that person's own judgments, suggest that people do not effectively utilize the information available to them in inference tasks (Dawes, 1975; Cohen, 1982). Other laboratory results suggest possible causes. For example, people tend to ignore later evidence that contradicts a favored, or earlier, datum and to double count redundant evidence (Schum and Martin, 1981). Also, people commonly ignore statistical, or "base rate", data and overweight unique or problem-specific factors (Kahneman and Tversky, 1972). Both of these observations suggest the predominance in natural reasoning of non-statistical, causal models (Johnson, 1985). Results can be distorted, and overconfidence can occur, when false analogies between the system and the model influence conclusions. When people do attempt to make statistical judgments, moreover, estimates may be biased by the ease of recall (or "availability") of a particular class of events in a mental sampling (Tversky and Kahneman, 1973).

Assess Quality of Conclusions. A number of studies show that people consistently overestimate their degree of certainty regarding predicted events and estimated quantities, even in areas where they are (rightfully) regarded as experts. While there is some evidence that experts (as opposed to college sophomores) are less susceptible to overconfidence (Lichtenstein, Fischhoff, and Phillips, 1982), other research indicates that the difference between expert and novice is slight (Kadane and Lichtenstein, 1982). When inference proceeds in stages (e.g., deriving the probability of being hit by enemy fire from information about the range of a threat, which is derived from bearings data), people often simplify the process by acting as if conclusions at earlier stages (e.g., range) were known to be true, rather than merely inferred (Schum, DuCharme, and DePitts, 1973). Similarly, the probability of a detailed hypothesis or scenario is likely to be judged higher than the probabilities of its components (Tversky and Kahneman, 1983). The latter effect may arise because additional details increase the match between the hypothesis and the user's mental models or knowledge structures (Leddo, Abelson, and Gross, 1984).

Option Generation. People segment complex options into "natural" components, and treat the elements as if they were independent choices, leading to suboptimal portfolios (Tversky and Kahneman, 1981). There is a tendency to formulate options in terms of immediate actions that span only a short timeframe rather than as long-term policies, and to overlook, as a result, the cumulative risk of pursuing a given course of action over a long period of time (Slovic, Fischhoff, and Lichtenstein, 1978). Individuals differ in the degree to which they consider future choices in current planning (Streufert and Streufert, 1981) and in the number of options they generate (Driver and Monk, 1976). Ingrained ways of viewing a problem tend to hinder the generation of novel and creative solutions (Pitz, Sachs, and Heerboth, 1980).

Generate Possible Outcomes of Options. In considering what might happen if a particular option is adopted, people are subject to biases based on their internal causal models, as well as biases in recall, such as a heightened tendency to remember salient events or events that occurred very late or very early in a sequence.

Assess Uncertainty of Outcomes. Some of the biases which affect situation assessment may also occur when predictions are made contingent on a particular option. Additional pitfalls, however, include the effects of "wishful thinking" (e.g., higher probability assessments for high utility outcomes) or overcautiousness (e.g., lower assessments for high utility outcomes). According to Einhorn and Hogarth (1984), the size of these effects will depend on the degree to which decision makers lack confidence in the probability estimates. This, in turn, may depend on the degree to which evidence for an estimate matches the type of evidence represented in user knowledge structures. An additional set of biases involves distorted conceptions of randomness in everyday judgment, e.g., the "gambler's fallacy" where a sequence of similar outcomes, which are in fact independent, is thought to increase the likelihood of a different outcome on the next trial. Fallacies of this sort may be inevitable by-products of powerful top-down or expectancy-driven processes of pattern recognition (Lopes, 1982).

Assess Value of Outcomes. Decision makers do not typically consider all the potential outcomes of an action together. Rather, outcomes are grouped into "mental accounts" corresponding to natural objects or causal relations, and choices may depend critically on the particular grouping that is adopted (Kahneman and Tversky, 1982). An additional cognitive simplification is achieved by representing an outcome in causally relevant terms, by the *difference* it would make relative to some reference point. Decisions may be significantly affected by the choice of reference levels, since the same outcome may be regarded as a gain or as a loss. For example, the outcome of a defensive tactic may be encoded as 400 men saved (relative to the number who would have died had nothing been done) or as 200 men lost (relative to the status quo). An important finding by Kahneman and Tversky (1979) is that decision makers are more likely to take risks when outcomes are represented as losses than when they are represented as gains.

Select an Option. Heuristic procedures may be adopted which reduce the cognitive effort that would be required in a thorough consideration of every option. Such heuristics have implications for the way decision makers search information. In Elimination by Aspects (Tversky, 1972), for example, search is organized by evaluative attributes. Attributes are considered serially in order of importance; options falling below a cut-point on an attribute are eliminated at each stage, and not considered further. In this strategy, an option might be eliminated for missing a cut-point on one dimension even though it scores very highly on other dimensions. Tradeoffs, or compensatory relations among dimensions are thus not considered. In another heuristic strategy, called "satisficing" (Simon, 1957; Svenson, 1979), information search is organized by options. The decision maker considers a sequence of options until he finds one that clears the cut-points he has selected on relevant attributes. Here again compensatory relationships are ignored. Payne (1981) has suggested that these information search strategies may correspond to the way decision makers organize knowledge.

2.3 Basis for Personalized Features

How are the users of decision aids likely to differ in their approaches to decision making and problem solving? What are the consequences of such differences for success in task performance? And how should aids be personalized so as to enhance both user acceptability and quality of performance?

We consider, briefly, two general ways in which decision makers have been thought to differ from one another:

- o in the parameters and structure of a prescriptive model based on their personal beliefs and preferences; and
- o in the heuristic strategies, decision processes, and cognitive styles which they adopt in problem-solving.

The interplay of findings from these areas helps define the potentialities and limitations of personalized decision aiding.

2.3.1 Individual prescriptive decision models. Ironically, a driving force in the evolution of prescriptive theories of decision making has been the need to accommodate individual differences. An objective rule for betting in games of chance, maximization of expected value, applies only where probabilities of outcomes can be mathematically defined (as in rolling dice) and where the desirability of outcomes is physically measurable (e.g., by money). Generalizations of this basic rule to situations where those conditions do not hold have led to the modern technique of decision analysis (cf., Edwards, 1954, 1961; Raiffa, 1968; Brown, Kahr, and Peterson, 1974). Von Neumann and Morgenstern (1947) formalized the notion of a subjective dimension of value, i.e., utility, and extended it to individual preferences among probabilistic states of affairs. De Finetti (1937/1964) and Savage (1954) developed formal systems for the quantification of an individual's "degree of belief", or subjective probability, about uncertain propositions, and developed axiomatic justifications for the merging of utilities and subjective probabilities into a new prescriptive rule, maximization of subjectively expected utility. More recently, rigorous techniques have been developed for combining subjective preferences with respect to individual components of value into a single multiattribute utility measure (e.g., Keeney and Raiffa, 1976).

The prescriptive force of decision analysis, in this form, is not to dictate to an individual in any absolute sense what he "ought" to do or believe. Rather, it indicates what choices and beliefs are logically consistent with other preferences and beliefs which he chooses to accept (cf., French, 1979).

These elements of personalization are by no means shared by all prescriptive approaches. Techniques in operations research (e.g., cost/benefit analysis) commonly purport to be "objective" and "value free" (Watson, 1981). The approach to decision analysis described above, however, has two important implications for personalized aids:

(1) Decision-analytic aids do not address only the part of a problem that can be objectively measured. Actual decisions nearly always involve a number of "soft factors" (e.g., uncertainty about the intentions of a business competitor or of a military foe; the relative importance of different objectives, like money and prestige). The decision maker's own experience may be the only source of relevant information in these matters, while an exclusively "factual" approach could be fatally incomplete. Aids which combine subjective and objective inputs must accommodate individual differences among users in assessments of uncertain states of affairs, attitudes toward risk, and tradeoffs among competing objectives.

(2) The second point is equally important, though far less widely recognized. Just as it does not prescribe inputs, decision theory constrains, but does not dictate problem structure. Typically, there is more than one way to express the probability of a hypothesis in terms of probabilities for other propositions; and there are multiple decompositions of the utility of an option into preferences for separate attributes. A good structure for a particular decision maker breaks the problem down into components about which that decision maker has either objective data or personal experience. Individuals might benefit differently from different analyses of the same problem.

In particular, it has been suggested that experts differ from novices in their capability to individually recognize a very large number of different problem situations (De Groot, 1965; Chase and Simon, 1973). Klein (1980) argues that experts tend to reason holistically, by analogy with previous similar experiences, rather than by explicit analysis and computation. Klein warns that imposition of analytical models may actually impair expert performance. In terms of decision theory, however, this distinction between experts and novices is accommodated by the notion of personalized problem structures. The expert might produce quite creditable holistic judgments of problem components which he has "seen before" but which a less experienced individual would need to analyze into more familiar elements. (Nonetheless, experts too are subject to error--particularly when a problem which appears familiar has novel aspects; cf., Sage, 1981. Experts may benefit from analysis of such novel components.) The implication is that if decision aids are to exploit the capabilities of each potential user, a variety of models, with different functions and at different levels of aggregation, should be made available (cf., Strub and Levit, 1974).

2.3.2 <u>Individual strategies in inference and choice</u>. Prescriptive decision theory does not provide a description of actual performance, either in probabilistic reasoning or in the evaluation of actions (cf., Einhorn and Hogarth, 1981). Recent research in cognitive psychology has shed light on the internal processes and structures which people employ in such tasks, and how they differ.

One line of research has explored the strategies people use in choosing among actions. Prescriptive theory requires that a single score for each option (its expected utility) be derived, which integrates all the available information about that option: i.e., its score on each of a set of attributes, or the probabilities and utilities of its possible outcomes. Several descriptive models of choice behavior have been proposed, however, which involve more partial samplings of the available data (e.g., Payne, 1973; Svenson, 1979).

In Tversky's (1972) Elimination-by-Aspects (EBA), for example, (as described in Section 2.2 above), the decision maker sequentially considers each attribute, establishes a threshold, and eliminates all options that do not score at or above the threshold on that attribute. In the decision strategy called "satisficing" (Simon, 1957; Svenson, 1979), the decision maker adopts a conjunctive criterion involving cutoffs on one or more dimensions, and compares successive options to the criterion until he finds one that is acceptable, whereupon he stops. These different decision strategies have different implications for the order in which people elect to receive information (Payne, 1973, 1976). Some strategies imply a search organized by options, others a search organized by attributes.

Individual decision makers vary in the decision strategies which are reflected in their information-seeking behavior and in their verbal protocols (Payne, 1976; Russo and Dosher, 1981). But little work has been done to discover whether these individual differences are consistent across time and tasks (Svenson, 1979); instead, emphasis has been on the role of task variables. For example, when there are a large number of choice options, decision makers tend to select routines like EBA which quickly eliminate some options by more approximate methods. They may then switch over to routines which integrate all the available information about the remaining options (Payne, 1976; Wright and Barbour, 1977).

Cognitive style has been regarded as a relatively invariant, abstract feature of a decision maker's approach to information across a variety of tasks (cf., Sage, 1981; Libby and Lewis, 1977). Perhaps the most common differentiation made in this literature is represented by a related cluster of distinctions between "analytic" and "heuristic" (Huysman, 1970; Mock, Estrin, and Vasarhelyi, 1972), "abstract" and "concrete" (Schroder, Driver, and Streufert, 1967; Sage, 1981), "systematic" and "intuitive" (Bariff and Lusk, 1977; McKenney and Keen, 1974), and "scientific" and "managerial" decision makers. The common thread is a distinction between preference for formal, explicit analysis, breaking a problem down into elements, and an approach based on global intuition, trial and error, or "common sense".

Unfortunately, there is little evidence establishing a relationship between these categories (based on self-descriptions) and actual information-seeking behavior (Zmud, 1979; Keen, undated). It has been found that systematics generally take more time and do better in decision problems than heuristics (e.g., Mock et al., 1972). Other results, however, have been inconsistent, showing that systematics prefer more information or less information and prefer either aggregated or raw data as compared to heuristics (cf., Libby and Lewis, 1977; Zmud, 1979). McKenney (quoted in Mock et al., 1972) states that the propensity to be analytical increases with task familiarity; Klein (1980) and Sage (1981) suggest that experts will be more intuitive.

A second problem in this literature is the failure to validate the claim that cognitive styles are task invariant. Studies which have attempted to do so have produced disappointing results (cf., Libby and Lewis, 1977), and recent reviews (Libby and Lewis, 1977; Sage, 1981) have shifted emphasis toward the influence of task features on decision styles adopted by the same individual at different times. Indeed, Hammond, et al., (1984) have shown that not only does the nature of the task influence decision style, but that particular ways of presenting task-related information can cause a shift toward analytic or intuitive methods.

In a few cases, "cognitive styles" have been defined in relation to actual cognitive behavior. Thus, Driver and Mock (1976) defined four styles by reference to two fairly specific processing dimensions: amount of information used and degree of focus. The latter refers to a tendency to consider only one solution, model, or option *versus* a tendency to entertain multiple possibilities. Streufert and Streufert (1981a) present criteria for "integrative" decision-making styles in terms of the number of, and length of time between, information requests and decisions based upon them. Streufert and Streufert (1981b) report that integrative decision making decreases with decision urgency, but is an inverted-U-shaped function of the amount of information available.

2.4 Implications for a Personalized and Prescriptive Aid

Descriptive work on human inference and decision processes has implications for both the personal and prescriptive aspects of decision aiding.

2.4.1 Personalization and efficient flexibility. "Flexibility" in and of itself is not a sufficient objective in system design. It is possible to make each of a vast number of logically possible information acquisition strategies equally easy, by allowing the user to indicate what he wants item-by-item. But such a system does not really facilitate the selection of *strategies* as such; to deal explicitly with all possible search orders would be beyond the time and capabilities of both user and device. The objective of personalization is to delimit the subset of strategies which an individual is most likely to prefer. Decision aids may then be tuned to facilitate explicit selection from this smaller group of strategies, while still affording the general "flexibility" of an arbitrary item-by-item search sequence. Such aids are *efficiently flexible* in their responsiveness to likely user needs.

The most natural way to acquire and process information can vary as a function of the individual and the task. Several such forms of variation seem to occur frequently enough in performance to justify an aid design which facilitates their employment:

- o search organized by options or by attributes,
- o decision rules based on cutoffs or tradeoffs,
- o level of aggregation of information.

In addition, it seems desirable that an aid facilitate differences involving:

- o focus on one or many options,
- o desired amount of information, and
- o time into the future over which planning takes place.

There is little evidence that particular individuals are consistent across tasks in these preferences, and some indication that they are not. In the case of gross categories like "intuitive" and "analytic", moreover, there is no reliable mapping of traits onto system design features and certainly no indication of how different traits interact (cf., Huber, 1982).

2.4.2 Prescriptive aiding. The danger inherent in complete flexibility for the decision maker is, of course, the high likelihood that one or more of the common cognitive biases described in Section 2.2 will result. As a safeguard against this, two types of prescriptive aids may be introduced: channeling and advisory prompting. The difference between them is largely one of tactics. *Channeling* is implicit and proactive, in that it encourages users, in advance, to adopt variants of their own preferred strategies which are less susceptible to biases and fallacies of judgment, by structuring the problem in such a way that those variants become natural and simple to execute. By contrast, *advisory prompting* is explicit and reactive, in that the system monitors the tasks performed by the human, identifies steps taken that are likely to lead to error, and prompts for the addition of procedures that mesh with the preferred strategy but would minimize the possibility of error; it also monitors tasks performed by the computer and prompts where a human contribution might improve results. Thus, in advisory prompting the computer senses weaknesses in a line of reasoning, whether its own or the user's, and offers help. Both channeling and advisory prompting may be viewed as examples of low-level expert systems.

Some examples of how the prescriptive aiding techniques of channeling and advisory prompting can be blended into a personalized system are given below.

While users should be able to organize displays around a variety of meaningful user-designated objects, the aid should facilitate the use of *decision-related* objects for this purpose. For example, channeling can facilitate clustering of options by their performance on a selected evaluative criterion. When an intermediate result or conclusion is uncertain, the sources of its uncertainty should be explicitly indicated. Evidence for a result should be available for display along with the result. Inferential relationships in the database can be "mapped" by menus, which permit tracing a process of reasoning from its sources of evidence to its final conclusion.

Research in cognitive psychology suggests that humans tend to seek additional confirming evidence for a favored hypothesis. An advisory prompt might monitor a user's pattern of information requests, examine its own model of the problem in order to draw inferences about the hypotheses the user has in mind, and prompt the user if evidence or hypotheses exist which the user has failed to consider but which may have an impact on his conclusions.

Humans often find it difficult to assess the overall credibility of a conclusion based on several steps of reasoning; they simplify by ignoring the uncertainty at early stages. Prompts might warn users, when they appear to be acting as if a particular hypothesis were known to be true, that a number of stages of uncertainty must be kept in mind. The same type of caution might be appropriate when a compound, or conjunctive, hypothesis is being considered.

The user might be notified when two information sources, both of which are regarded as credible, have contradicted one another. He might then choose to readjust one or both credibility assessments downward. An advisory prompt might notify him on future occasions when either of the (partially) discredited sources is involved in an important conclusion.

While the aid should permit user adjustment of any meaningful values employed in the database, channeling should selectively facilitate adjustment of values about which users are likely to have information not available to the computer. Values to be adjusted could be decomposed by channeling into parameters about which users are likely to have reliable intuitions. Automatically computed values could be displayed as a reference, so users can focus on the appropriate direction and magnitude of the adjustment (based on the new evidence) and not have to integrate all the evidence to come up with an absolute value.

Humans tend to combine evidence by a process that is more like averaging than like proper Bayesian inference. When adjustments fit an averaging pattern, advisory prompts might remind subjects to consider what conclusion a new bit of evidence favors, before performing an adjustment.

Users could be prompted when information they possess may be of significant value, i.e., when (1) there is incompleteness of evidence or a conflict among lines of reasoning in the computer model of the problem; (2) the user has potential access to relevant information; and (3) the result is expected to have an impact on choices among actions and ultimate payoffs.

Channeling could facilitate relatively long time horizons for planning (e.g., by displaying appropriate scaling). Simultaneous specification of all components of a complex option could be facilitated by channeling. Displays should permit generation and simultaneous comparison of multiple options. Channeling should facilitate generation of options which include future choices or contingencies.

Short-range planning might be more appropriate in some situations (e.g., where feedback is continuous and mistakes can be easily and quickly corrected), while long-range planning would be more suitable in others (e.g., where a risk appears small unless it is considered cumulatively over the long run). Advisory prompts might recommend that the user consider a shift in the time horizon under appropriate circumstances.

Users should be prompted if they have generated and evaluated a complex option piece-by-piece and if overall optimality would be significantly improved by considering the option as a whole.

The user should be prompted if only one option has been considered, but another option exists which is superior on at least one dimension.

The user should be prompted if contingency plans have not been incorporated in an option, but significant new information is likely to become available during its execution.

Channeling could draw the user's attention to tradeoffs between different evaluative dimensions by displaying scores for an option on more than one dimension concurrently (e.g., costs *and* benefits). The aid's action recommendations should be explained by itemizing how options differ on all significant dimensions. Channeling should encode and display outcomes in terms of more than one reference point (e.g., assets lost, assets saved).

Humans tend to employ simplified choice schemes that disregard tradeoffs. An advisory prompt might notify the user when he has eliminated an option because it fails to achieve a specified level on a favored evaluative dimension, if that option has significant advantages on other dimensions. The user might be told how much stretching of his specified criterion is required to readmit the rejected option.

An advisory prompt should occur when a user entertains an option which is dominated (inferior or tied on all dimensions) by other options.

While users should be free to designate any item or variable in the database as a criterion for alerting, alerts should also occur on a prescriptive basis. Users should be prompted when events occur or facts are learned which have high impact within an appropriate prescriptive model, e.g., which disconfirm previously well-supported inferential hypotheses or which significantly affect choices among actions.

The distinction between channeling and advisory prompting is based to some extent on the source of the potential bias or error. Using the terminology of behavioral decision theory, if "base rate data" (i.e., a body of research findings) suggests that errors commonly result from certain ways of representing a problem, organizing the variables, assessing uncertainty, evaluating outcomes and making choices, channeling can be built into the aid to increase the chances that the user will adopt amended versions of these procedures that avoid all or most of the errors. On the other hand, if "individuating data" (i.e., the actual procedures and judgments of the specific user) appear to be moving the user into less-than-optimal choices, advisory prompting can explicitly point this out and suggest alternatives that deviate minimally from the user's originally preferred strategy (again, preserving the user's freedom to ignore the advice). In this way, the flexibility provided by personalization of an aid can be tempered by the prescriptive techniques of channeling and prompting without imposing undesired constraints on the user.

3.0 INTRODUCTION TO NEW DECISION MODEL

As indicated in Section 1.1, the prototype aid serving as a context for this work was changed from one dealing with a submarine commander's decision about when to launch an attack on an enemy target, to one dealing with a personnel manager's selection of a new hire from a number of applicants. Aside from the obvious difference between the two, namely, that the first deals with military tactics while the second deals with a broader civilian (as well as military support) decision situation, there are other, more fundamental differences between the two types of decisions that should be pointed out before the new system is described in detail.

3.1 Degree of Model Generality

The most significant difference is that the new decision problem is one that lends itself to a much more generic model, applicable to a wider variety of situations. The submarine attack model is typical of military tactical situations in which the decision maker is faced with a clear tradeoff between firing early or waiting for more information (which may increase the probability of his success but simultaneously decrease his own survival probability). This type of tradeoff occurs in many military tactical situations, but the temporal pace of the action and the factors that must be built into the model vary considerably. These tactical models must be largely tailored to specific situations, hence their generic features are severely limited.

The personnel selection problem, on the other hand, is typical of a wide variety of decisions that involve multiple evaluative criteria or objectives. Thus, if properly constructed, the system can be made applicable to other decisions such as choices among political candidates, policy options, investment portfolios, R&D programs, military plans, and many others. This generality can be accomplished by keeping the modular process programs entirely separate from the database. Thus, there can be modules that allow the user to build his own preference model, to accomplish word processing functions while building the model, to search the database in various ways, to organize the data in various ways for analysis and display, to enter new data or be alerted when new data are entered by someone else, and to provide channeling and advisory prompting prescriptive aids--and these modular programs can operate on any type of data that are germane to the specific decision problem.

3.2 Real Time and Stress

Another important difference between the two decision situations is that in the submarine attack decision, real time plays a central role in the way the problem develops, and in the decision itself, and contributes to the build-up of stress in the situation. In the personnel selection decision on the other hand, although there may be a real time deadline for the decision, the process itself is largely self-paced, under the control of the decision maker, and stress plays a negligible role in the situation (although there may be stressful components in other applications of this generic model). In the submarine attack problem, the firing decision evolves over a period of time during which (in most cases) more and more information becomes available, and information seeking is always an important option to be considered. In the personnel selection decision, although it is sometimes possible to obtain additional information, the emphasis is on evaluating existing data in a variety of ways in order to select an option.

In the submarine case, once an action has been selected and performed, the problem essentially is re-set and may begin again later with a new target. In the personnel selection case, the problem often continues after a choice is made, since multiple choices are typically possible. Here, subsequent choices may be made from among fewer options, or new options (and new data) may be introduced into the decision situation. Thus, in this respect the personnel selection decision offers a richer set of conditions under which the decision process may be examined.

3.3 Inference vs Choice

Although it is often difficult to separate the two components of inference and choice in real-life decisions, there are certain key distinctions between them. Inference is concerned mainly with assessment of evidence related to the relative likelihoods of various hypotheses being true, and the judgments being made are usually in the form of probabilities. Although these probabilities usually enter into the choice process, the distinctive feature of choice is the assessment of preferences regarding the various options available, or the predicted consequences or outcomes of these options. In the submarine attack decision, the more significant component was that of inference (about enemy position and intent), while in the personnel selection decision, the more crucial component is that of preference assessment.

3.4 Availability of Objective Data

In the submarine context, there is little or no opportunity for the user to assess and adjust the validity of his decision model by reference to on-going results of applying the model. The personnel selection decision, on the other hand, is typically much richer in terms of its database of on-going results. The database can include data on the characteristics and performance of current and past employees (in addition to applicant characteristics), so that the user can in fact test his model against previous data if he desires. As a result of this feature, the personnel selection application offers a large set of opportunities for individual variations in data organization and display. Users may change the features being considered, their importance, the sequence in which they are examined, and the way they are displayed, as well as the level of detail at which the analysis is conducted. As pointed out in Section 2.4, safeguards in the form of prescriptive aids must be provided to minimize the judgmental biases that could emerge as a result of this flexibility, but the overall aims of the project are well served in the context of the new application area.

4.0 SYSTEM DESCRIPTION

4.1 High Level System Design

The conceptual design of the personalized evaluation system has been organized around two closely related concerns: (1) Users of a large database of options may differ in the extent to which they know what they want or do not want, in the naturalness with which they make holistic vs. analytic judgments of preference, in the decision rules and information search strategies they favor, and in the extent to which they seek to validate choices by examining low-level evidence. (2) In the very experience of examining and evaluating options, user preferences may grow increasingly determinate, with a corresponding shift in decision and information search strategies. As a consequence the system is designed to be *personalized*, that is, to conform to a user's preferred cognitive style. The user of such a personalized aid benefits from not having to force his/her thinking into an uncomfortable mold, but at the cost of relying on a strategy that, although familiar and comfortable, may be suboptimal. To guard against this risk, the aid is also designed to be *prescriptive*, to warn the user of information that may have been ignored, or errors in judgment that may have occurred.

The system is built upon a set of elementary modules, consisting of a knowledge module, four cognitive interface modules that process and make changes in the information stored in the knowledge module, and a fifth cognitive interface module whose function is to alert the user when actions taken via the other modules may differ significantly from some normative benchmark.

The experienced user can access these modules directly, via a user-friendly interface that features menu-driven, mouse-controlled graphical *displays*. Users may also wish to make use of *guides*, whose purpose is to step the user through the elementary modules in accordance with one of a set of available strategies corresponding to different cognitive styles.

4.1.1 <u>Overview of elementary modules</u>. A set of six basic modules, interconnected as shown in Figure 2, form the basis of a generic decision aid. Depending on specific context, the importance attached to the functions of the modules may vary. Our focus in this report is on an evaluation aid (specifically, for personnel selection). This overview describes the generic functions of each module; the next section describes how each module is implemented in the specific context of personnel selection, and gives examples.

1. <u>Knowledge Module</u> - This module encodes the system's knowledge about the decision context. Knowledge includes specific information about the decision problem (e.g., options and facts about options), general knowledge about the problem domain (e.g., preferences among evaluative criteria), procedural knowledge about how the decision process is to be carried out, and knowledge about the current status of the decision process. This knowledge base serves as input for, and is altered by, the cognitive interface modules.

2. <u>Adjust Module</u> - This cognitive interface module allows the user to add to or change the system's database of specific problem knowledge and general knowledge about the problem domain. The user can also create or alter procedural knowledge, i.e., knowledge about how the database is to be manipulated. Inputs may be specified in different ways and at varying levels of "fuzziness," depending on the user's preference.

3. <u>Decide Module</u> - This cognitive interface module allows the user to apply the system's procedural knowledge to the system's database. The user may specify one of several decision making strategies or models (e.g., multiattribute utility evaluation, elimination by aspects), corresponding to different cognitive styles, for database manipulation and choice. Evaluation proceeds to the degree permitted by the level of specificity of user inputs, and whatever implications can be drawn are displayed.

4. <u>Select Module</u> - Using this cognitive interface module, the user may select a subproblem on which to focus, a subset of information to be displayed, or a subcategory of the database to be adjusted.

5. <u>Alert Module</u> - This cognitive interface module prompts the user when events occur or facts are learned which may cause significant changes in user decisions. This function is most important in real-time decision aids, when rapid assimilation and incorporation of incoming information is essential.

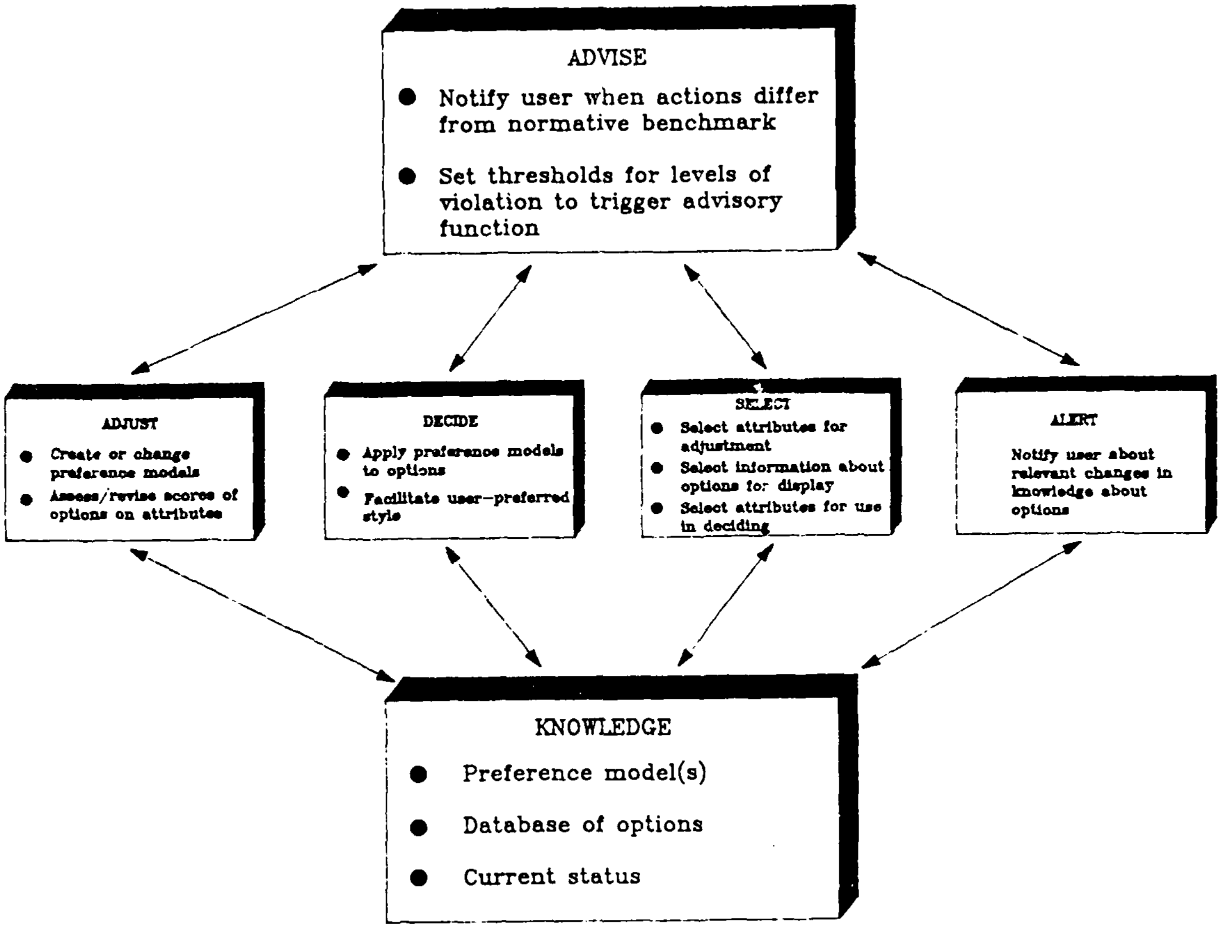


Figure 2: Basic Modules of Personalized Decision Aid
(as applied to Personnel Selection Aid)

6. Advisory Module - This cognitive interface module prompts the user when he or she appears to be using a strategy or a user-computer task allocation scheme which may be suboptimal according to some normative benchmark.

4.1.2 The Guides. A *guide*, as its name implies, has the function of directing the user through the basic functions in accordance with a given decision strategy. Thus, each guide is tailored to a particular strategy, and the cognitive style of the user determines which guide or guides (s)he chooses to invoke. The guides will in general be adaptive, enabling the user to observe the implications of certain inputs and, if necessary, cycle back to change them. Each strategy is subject to its own set of possible biases, and an important function of the guide is to inform the user when the possibility of normative violations occurs.

4.2 Prototype Personnel Evaluation System: Elementary Modules

As discussed in Section 3.0, the personnel selection context has several distinguishing characteristics which affect the design of a decision aid. The aid is focused on choice as distinguished from inference. In addition, time stress and the incorporation of uncertainty are of secondary importance, while data organization and display are of prime importance. In this section, we discuss both the elementary modules and the guides as they apply to the aid under development. The aid is generic in that it can be used in any problem domain sharing the above characteristics.

4.2.1 Knowledge module. The knowledge module consists of three components. (1) First is an option database of context-specific knowledge. In the case of personnel selection, we would have a database of individuals (job applicants) and their relevant characteristics (salary demand, years of experience, etc.). This part of the knowledge module is, in fact, the only aspect of the system that is specific to personnel selection as distinct from similar choice contexts. (2) The second component of the knowledge module is a preference model or models, and an associated set of decision strategies, which capture the user's knowledge of his own preferences in the problem domain and his or her preferred method for using those preferences in the choice process. Preference models may include numerical weights or attributes, intervals or ratios of weights, rank ordering of weights, cutoffs, or direct evaluations of options. Thus, preferences may be specified by the user with varying degrees of "fuzziness" and may be incomplete in some or many respects. User-selected decision strategies may be based on multiattribute utility, elimination by aspects, satisficing, or dominance, and are the means by which options from the database are retained or rejected. (3) The third component of the knowledge base is information regarding the current status of the system. For example, the knowledge module will keep track of which options in the database are "live" and which have been eliminated from consideration (via application of a preference model by use of the *Decide* module). In addition, the user may have indicated that, although the model is specified in terms of a large number of attributes, (s)he wishes to evaluate options based only on some subset of attributes.

4.2.2 Adjust module. This module, which acts on the first two components of the database, has two major functions. The first function is to allow the user to make changes in the option database as more information is acquired (e.g., a candidate is no longer available, the performance of an option on an evaluative dimension needs to be changed in the light of new information). The second (and most important for a personalized decision aid) function is to create or change the preference models by means of which the options in the database are to be evaluated. It is this function that can most significantly be tailored to individual cognitive styles.

The adjust module allows the user to specify preferences in three basically different ways: (1) compensatory knowledge about the relative importance (and tradeoffs) among evaluative criteria; (2) cutoff levels, i.e., non-compensatory goals, on attributes such that candidates not meeting the cutoffs are rejected; and (3) "bootstrapping" or "policy capture" judgments which express the values of options directly. These three modes correspond to differences in the degree to which users prefer analytic versus intuitive and concrete approaches to choice. In addition, as noted, analytic knowledge in mode (1) may be expressed to virtually any degree of precision/imprecision or completeness/incompleteness.

4.2.3 Decide module. The function of this module is to apply a user-preferred decision strategy, and a user-defined preference model to the database of options, and evaluate and display the results. If a full multiattribute utility model has been specified (i.e., a complete set of numerical weights on all attributes), the system can display the most preferred alternative(s). If the model is only partially specified (i.e., user inputs of orderings, intervals and/or ratios of weights fall short of entailing exact values of weights), the system displays those implications that *can* be drawn from the information the system has. For example, the system can compute the feasible alternatives, i.e., those options that cannot be eliminated based on the available knowledge of the user's preferences. In addition, the system can perform a type of dominance testing; that is, given one alternative (hypothetical or from the database), it can compute which alternatives are known to be at least as good. Finally, the system can perform *elimination by aspects*, a choice strategy requiring only an ordering on the attributes and cutoff levels for each attribute.

4.2.4 Select module. This module allows the user to select: (1) aspects of the preference model for display or adjustment, (2) information about options for display or adjustment, and (3) a subset of the current preference model for application in choice.

4.2.5 Alert module. The function of this module is to notify the user of relevant changes in knowledge about options. This module is of primary importance in real-time systems in which the system must assimilate information about the outside world faster than it can be attended to by the user. Such a system must help the user to cope with "information overload" by alerting the user to possibly useful new information.

Even in the present context, however, information overload may plague the user of a large database. If new options are incorporated into the database, or changes occur in the data regarding old options, then the user might be alerted if (and only if) those changes have implications for the current "best alternative set."

A second mode of alerting involves user-specified alerts: for example, the system can be told to provide an alert if a candidate shows up with four years of programming experience.

4.2.6 Advisory module. This module functions as an overseer of the other modules, checking when a preferred user decision strategy may result in significantly suboptimal choices. (1) *Adjust*: For example, users would be prompted when inputs provided under the Adjust module are significantly inconsistent, and ways of resolving the inconsistency would be suggested. If the information provided by a user is too imprecise or incomplete for successful application of the preferred decision strategy, Advisory prompts would suggest additional inputs that are needed (e.g., the number of live options could be narrowed down from 100 to the desired 10, if only the order of importance of education and experience is indicated). Users might also be notified if small changes in user inputs would have a significant impact on choice. (2) *Decide*: in the Decide module, users applying elimination-by-aspects or satisficing would be prompted to reconsider an option which has been discarded because it fails to meet a cutoff on one attribute, but is outstanding in other respects. Conversely, the user would be notified if an option which is accepted, because it clears all cutoffs, is in fact dominated (i.e., there is an option set which is at least as good as that option on all dimensions and better on at least one dimension). (3) *Select*: Users would be prompted when user-selected attributes fail to capture significant variance in the option database. (4) *Alert*: Users would be prompted when user-defined alerting criteria fail to capture significant aspects of the current preference model.

In all cases, users would control the degree of significant of the problem that is to trigger an advisory prompt. Moreover, users are free to accept or reject any advice that is offered.

4.3 Current Status

This section describes in somewhat more detail selected functions in the personalized evaluation system that are currently implemented or planned.

4.3.1 Adjust.

4.3.1.1 Problem structuring--This function allows initial structuring of the problem, i.e., identification of the options to be considered and the attributes on which they are to be evaluated.

4.3.1.2 Entering compensatory/tradeoff information on attribute weights--The user can enter compensatory/tradeoff information on the relative importance of attribute weights in any one of three ways (or in any combination of the three):

- The Weights Screen - On the Weights Screen (Figure 3), the user can enter upper and lower bounds for each attribute weight. By setting the upper and lower bounds equal, a precise weight may be entered. The user also sees the bounds implied by all other judgments (s)he has made on this and any other screens. Figure 3 shows a sample Weights screen display, on which the user has indicated, for example, that the weight for the first attribute (Experience) should be between 15 and 35 on a scale from 0 to 100, with the other attributes weighted as shown.

- The Tradeoffs Screen - The Tradeoffs Screen (Figure 4) allows comparisons of relative magnitudes of attribute weights. One of the attributes may be specified as the standard, and other attribute weights are assessed relative to it. In the sample screen of Figure 4, the decision maker has indicated that the Education attribute should be given weight between 70% to 90% of that of the Experience attribute. The information is coded internally into linear inequality constraints on the attributes. Again, the decision maker can see the implications of all other inputs to the system (on this or any other screen) as they relate to relative magnitudes of attribute weights.

- The Rank Order Screen - On this screen (Figure 5) the user can enter information merely about the order of importance of attribute weights (e.g., that the first attribute should have higher weight than the second without saying any more about what those weights are). Once again, the implications of all user inputs for rank order of weights is displayed.

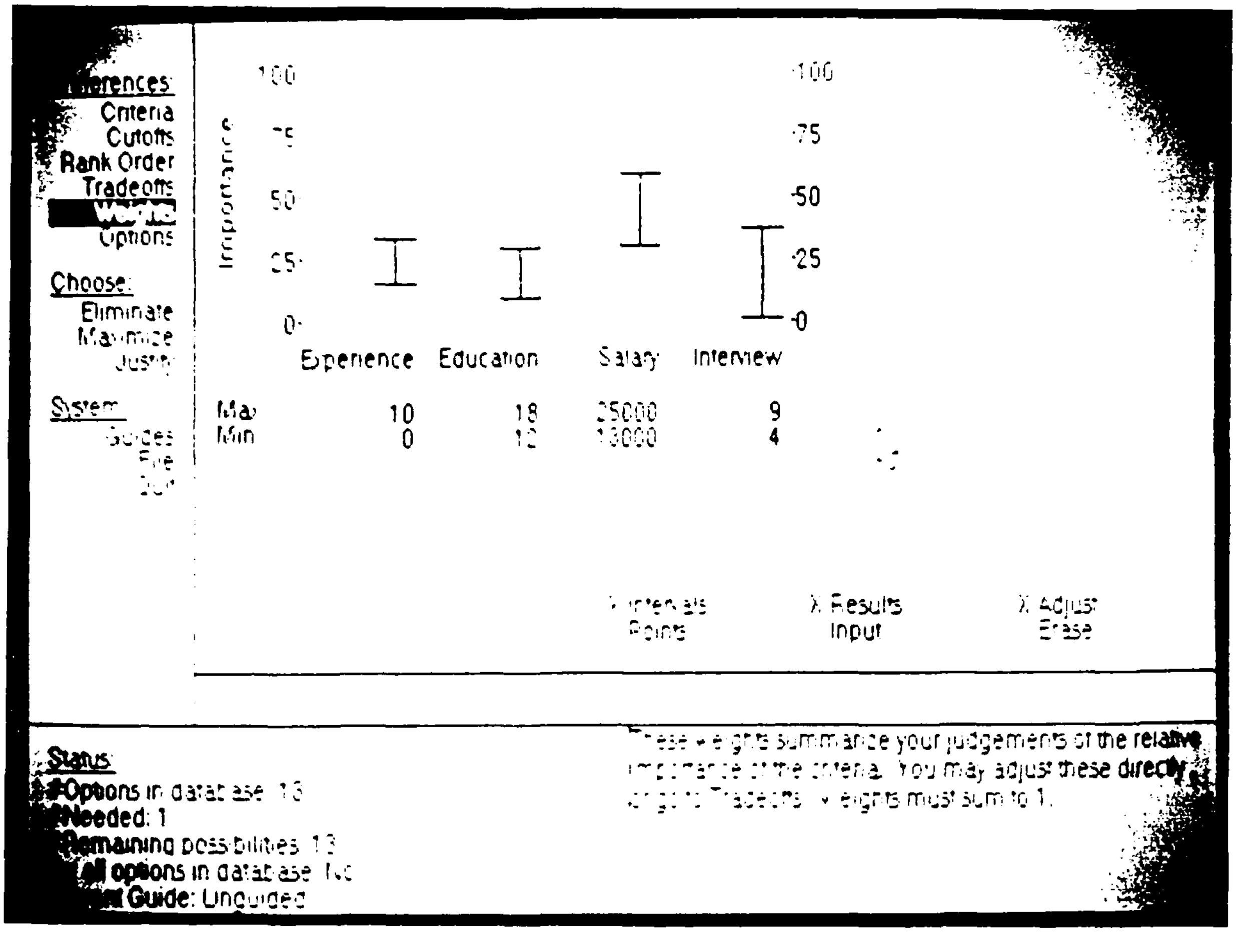


Figure 3: Weights Screen

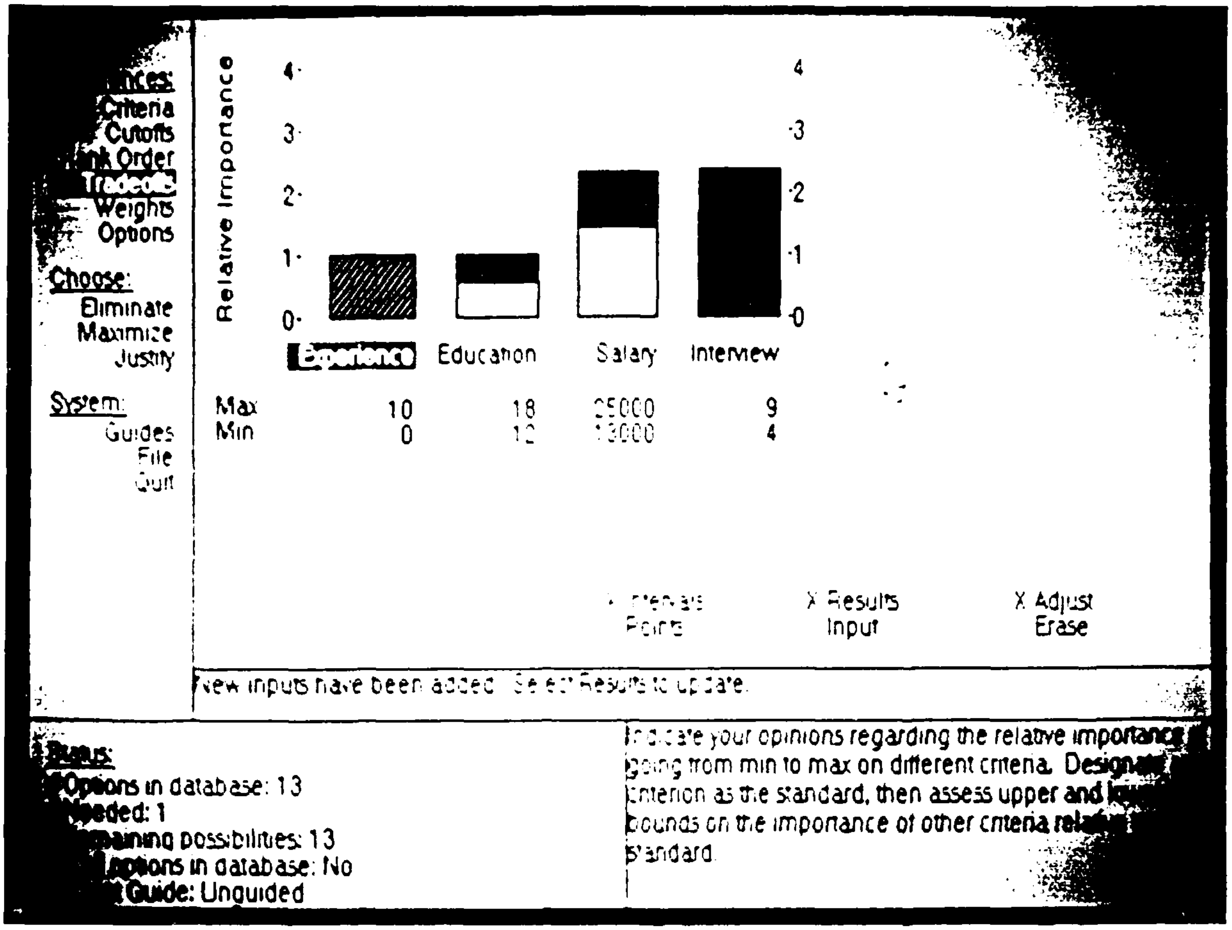


Figure 4: Tradeoffs Screen

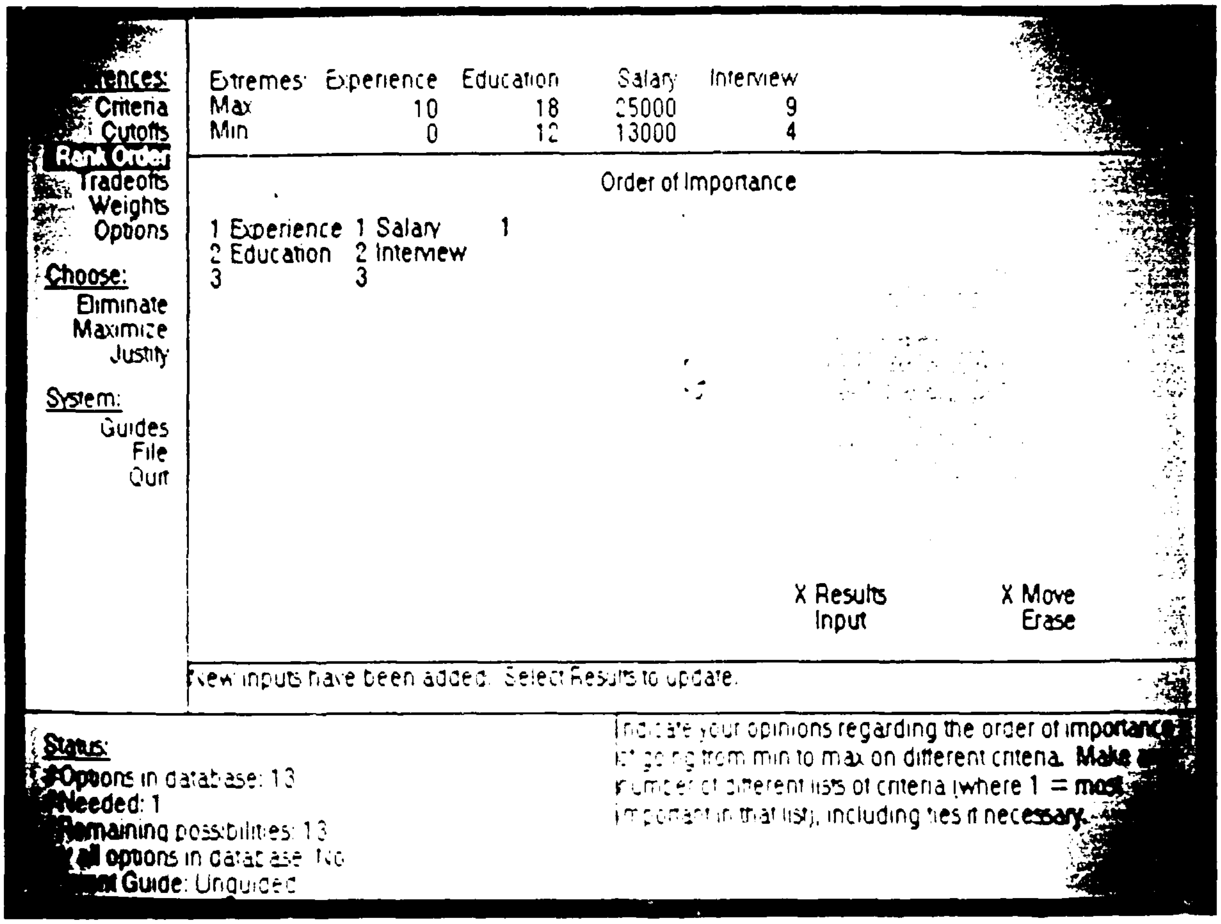


Figure 5: Rank Order Screen

Each of these screens allows a user to think about his or her preferences in a different way. Yet they are highly integrated, since the implications of all currently available information (entered from any of the above screens, or from the bootstrapping screen described below) can be displayed on each screen. The mechanism for computing implications across screens is linear programming.

The entering of information on each of these screens corresponds to building or changing a preference model.

4.3.1.3 Cutoffs on attribute scores--On the Cutoffs screen (Figure 6), the user can indicate minimal and/or maximal acceptable levels for any attribute, so that alternatives not meeting the cutoff are eliminated from consideration. Cutoffs can also be provided using the Elimination-by-Aspects function, described below.

4.3.1.4 Bootstrapping (planned)--On the bootstrapping screen, the user makes direct judgments about alternatives, either real or hypothetical. The user may place bounds on the score of the alternative (e.g., "between 65 and 80 on a scale of 100") or may make a direct comparison between two alternatives (e.g., "Jones would score better than Smith"). As for the above screens, bootstrapping information can be encoded as linear inequalities on attribute weights.

Bootstrapping is an indirect way of giving the system information on attribute weights. Hence, the Bootstrapping screen may be viewed as part of the Adjust module, and implications of the Bootstrapping judgments are stored as part of the Knowledge module.

4.3.2 Decide. By pointing to "Maximize" and clicking the mouse key, the user instructs the system to apply whatever knowledge about his preferences the system has gathered to the current set of options. Two settings are provided which influence the performance of this function: "# Needed" indicates the number of options which the user ultimately desires to choose; it may range from 1 to the number of items in the database (a

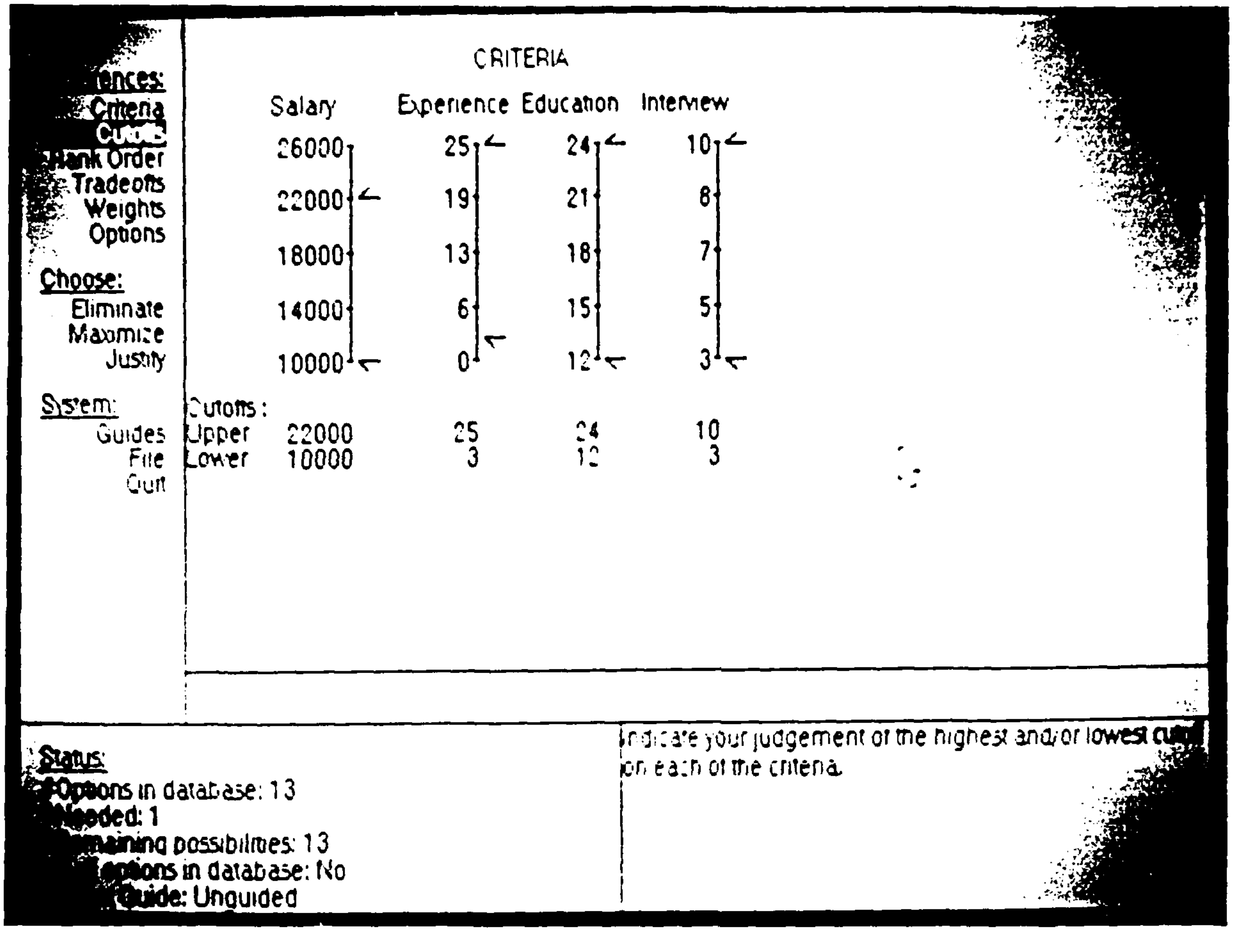


Figure 6: Cutoffs Screen

trivial choice problem!). The first time "Maximize" is selected, the preference model is applied to the entire database of options. The application of that model is likely to result in a smaller, weeded down subset of options which remains feasible or "live" (i.e., a set of options which is known to contain the desired choices, but within which further discriminations cannot be made based on present inputs). The user may, if he wishes, return to the Adjust screens, provide further inputs (or revise old ones), and then select "Maximize" again. Each subsequent selection of "Maximize" operates on the currently prevailing set of live options, further narrowing it down. The user has the option, however, of resetting this process by selecting "Try all options." In that case, the next use of "Maximize" operates on the original, full database.

By these simple commands, the user can implement any of a variety of choice strategies. For example, by setting cutoffs on additional dimensions between each use of "Maximize," he may successively eliminate options, through an elimination-by-aspects strategy. Any compensatory information will also be used directly by the system to eliminate options. The result of "Maximize" is always the set of feasible options, i.e., those that *could* be optimal given current information.

4.3.3 Guides. In addition to these basic functions, a variety of guides and special screens support the decision process. These involve functions not only from the Decide module, but also from Adjust, Select, and Advisory, orchestrated in a user-friendly dialogue that reflects typical decision making patterns.

4.3.3.1 Eliminate--For example, instead of performing elimination-by-aspects by means of elementary commands (as described above), the user can receive additional guidance through "Eliminate." This guide directs the user, in a highly flexible manner, through the following steps:

(1) Selection of attributes for inclusion in the choice process (by graphical pointing) (Figure 7);

(2) use of ordering screen to rank order the selected attributes, with prompts to elicit from the user a single connected ordering (Figure 8);

(3) use of cutoff screen to elicit cutoffs for the selected attributes (Figure 9);

(4) display of results on the EBA screen (Figure 10).

These steps are by no means rigid. For example, if he or she is satisfied with the already existing attribute selection, ordering, and cutoff specification, the user may proceed directly to step (4). At any time thereafter, the user may return to any previous step, make changes, and observe the results.

The EBA screen (Figure 10) functions as an elimination-by-aspects "spreadsheet." It displays the selected attributes in order of importance, the lower and/or upper cutoffs, and the number of surviving options at each stage in the process (i.e., after each additional set of cutoffs has been applied). In addition, an advisory prompt is provided which notifies the user if there are promising options which have been rejected. These are options which fall outside the cutoffs on an attribute, but score very well on other dimensions. In addition, the user is told by how much the specified cutoffs would have to be stretched to include these rejected (but promising) options.

The user can modify any cutoff directly on this screen, and the EBA will be recomputed, showing which alternatives are thereby excluded or re-included. By use of the mouse and the VIEW option, the user can "zoom" in on the details of any part of the EBA screen. For example, the user can view all database options in the vicinity of the lower or upper cutoff on any attribute, or he can view the set of promising but rejected options. The reasons for considering an option "promising" are also indicated. From the zoomed-in point, the user can scroll anywhere else in the database of options. The VIEW screen can also be used to modify cutoffs in a way that

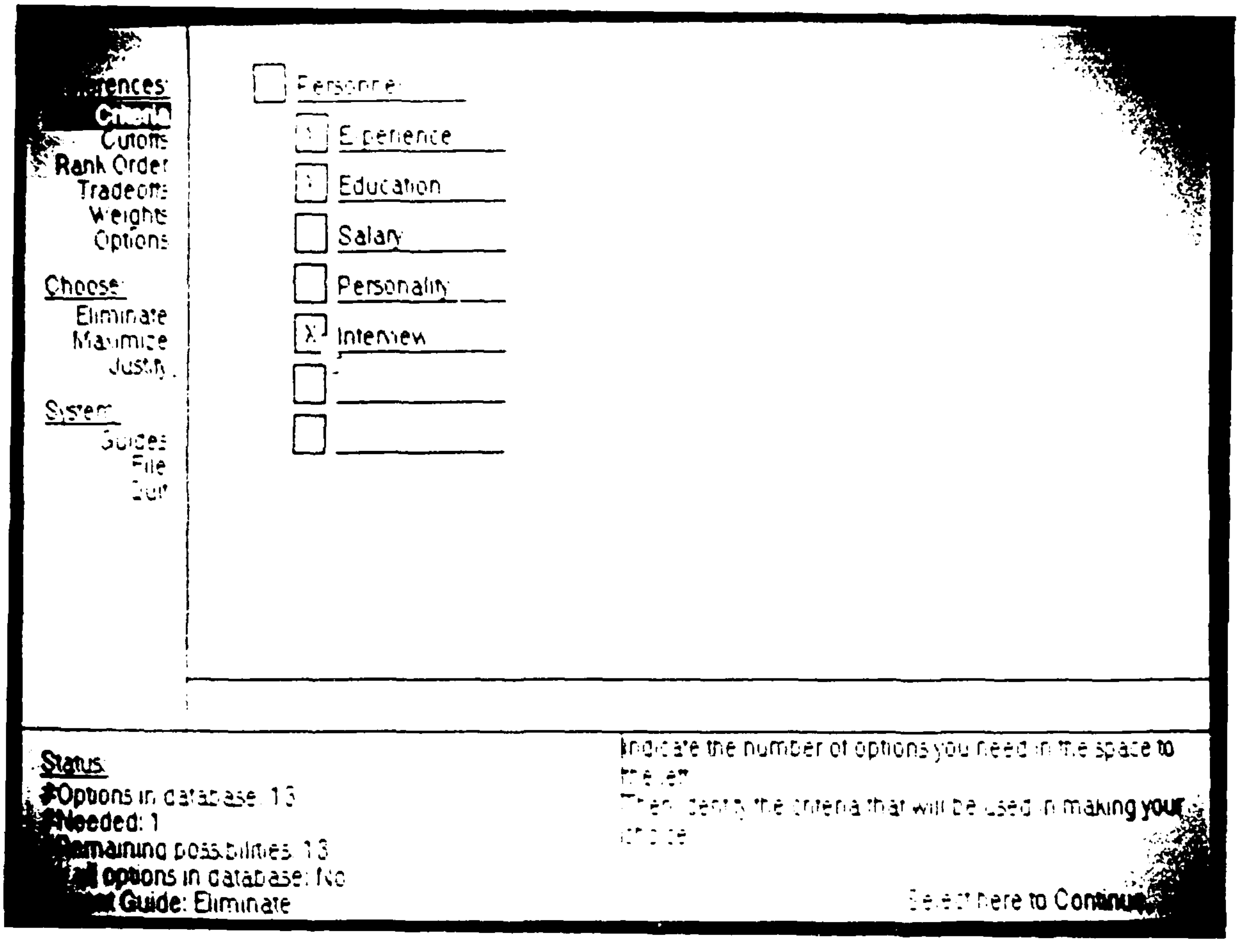


Figure 7: Selection of Attributes

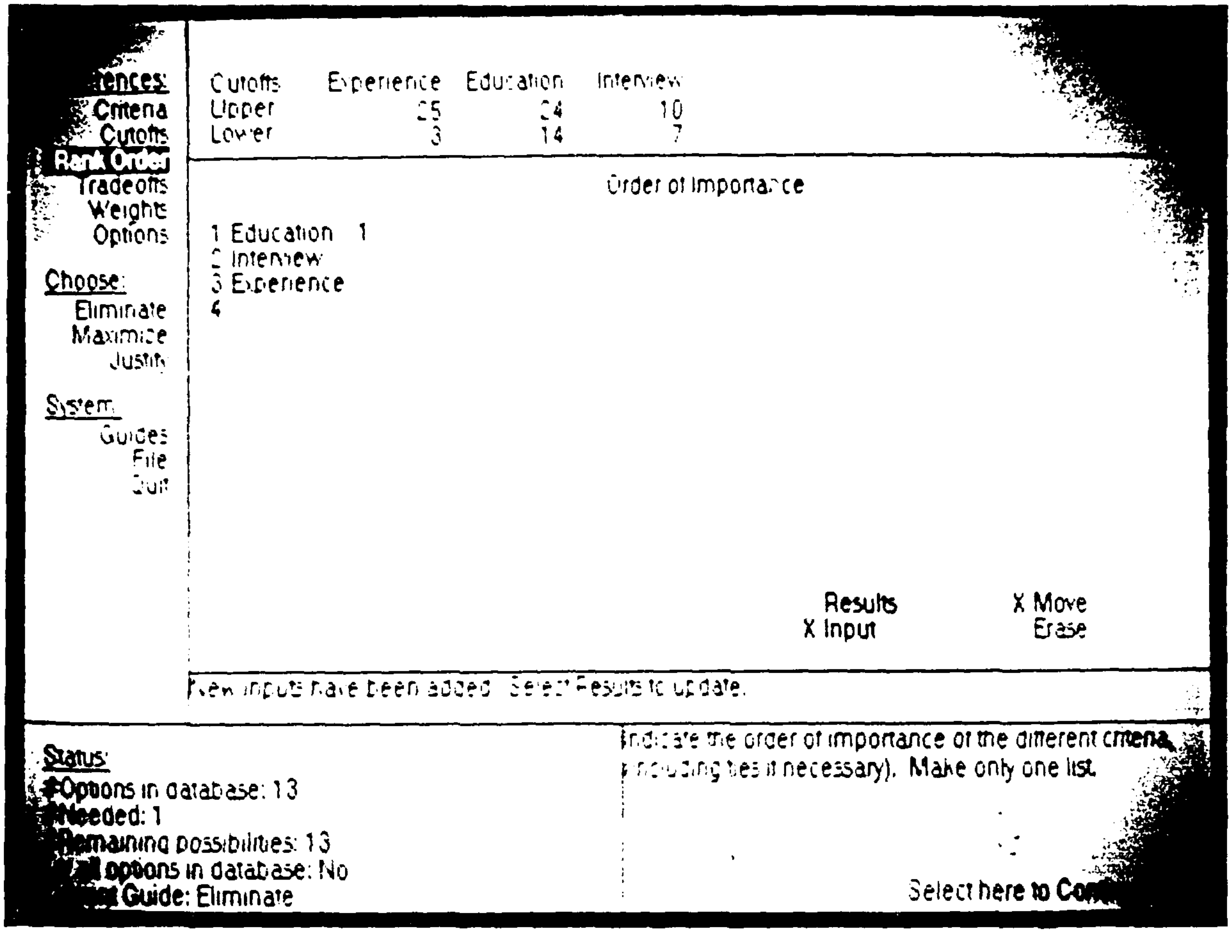


Figure 8: Rank Order Attributes

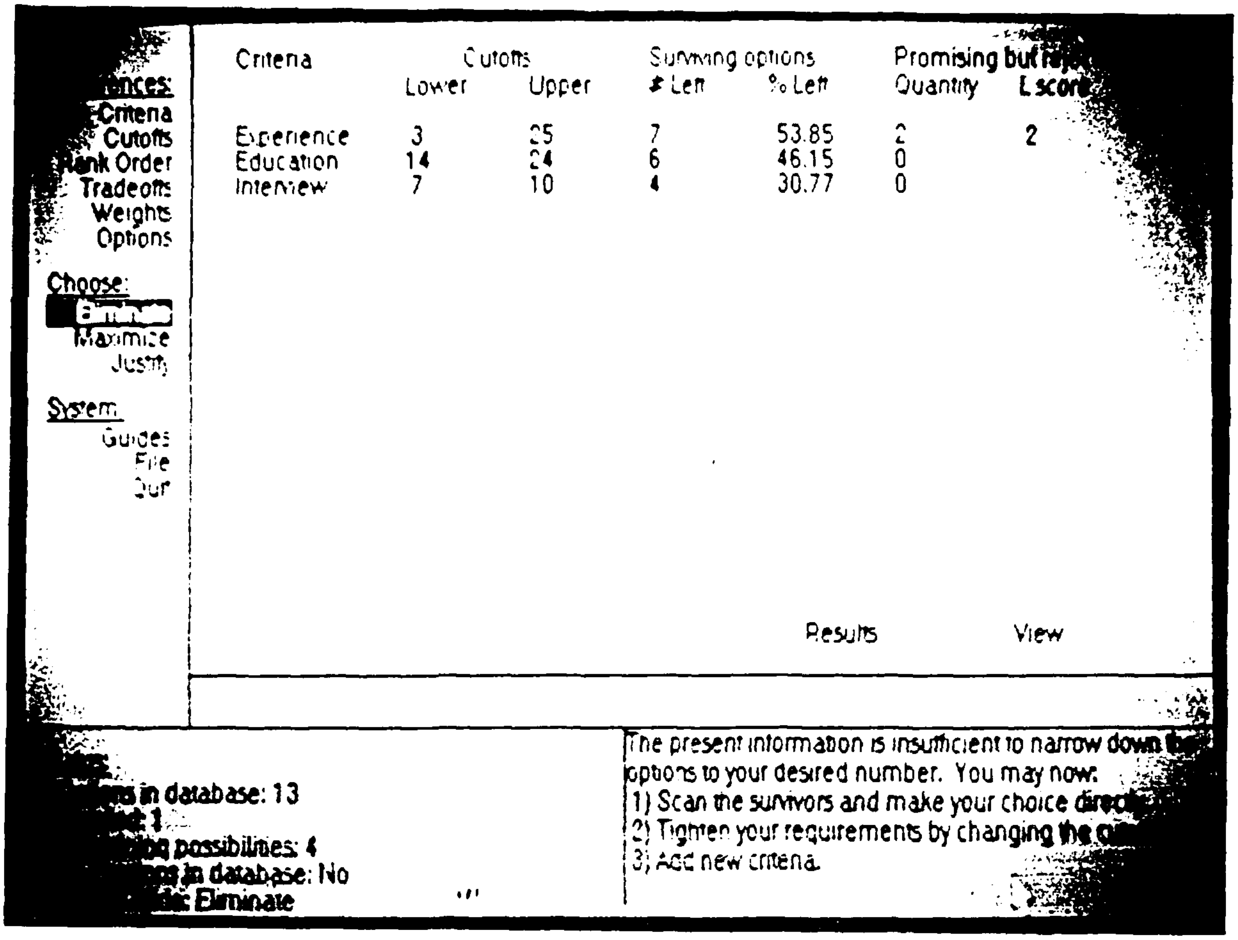


Figure 9: Attribute Cutoffs

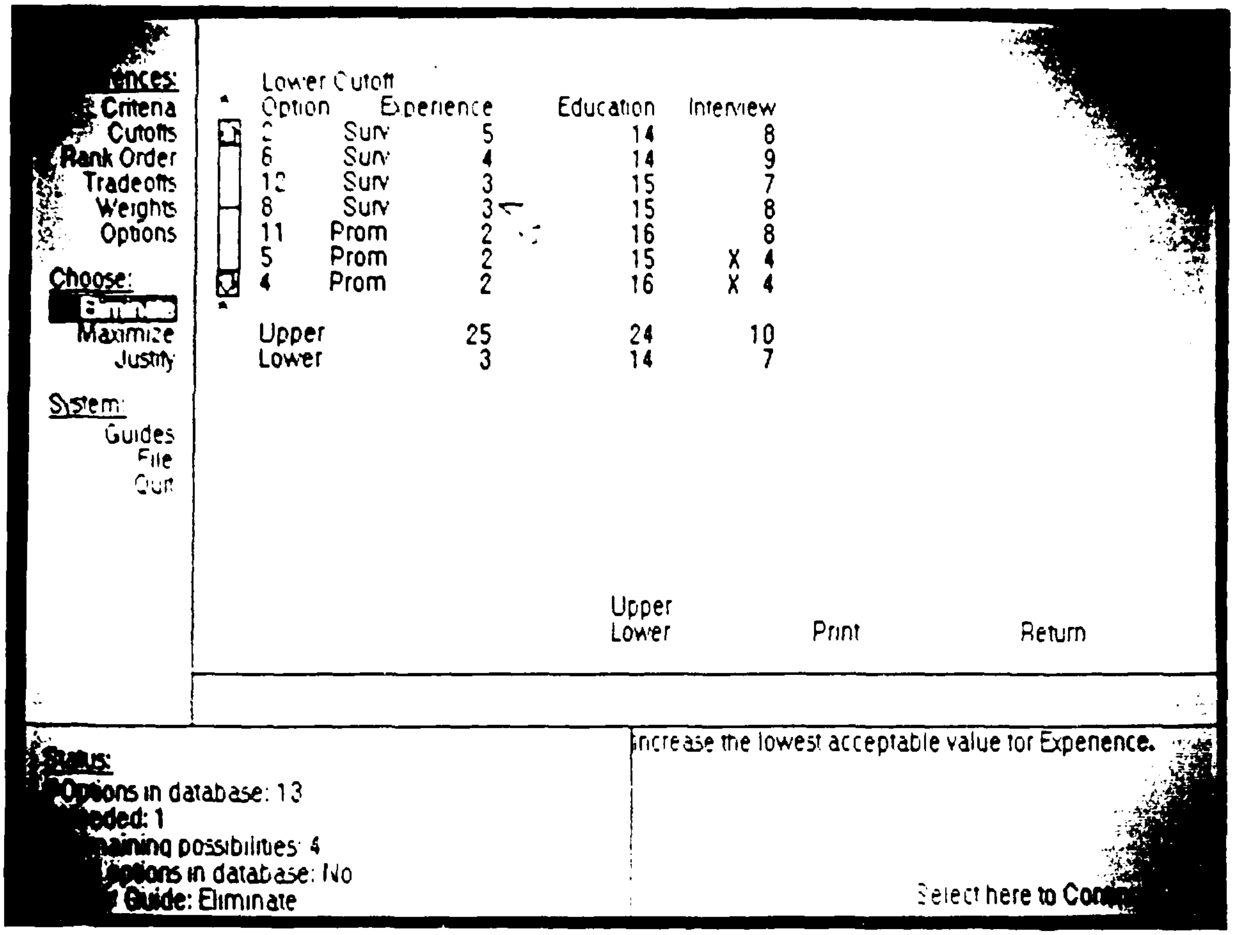


Figure 10: Eliminate by Aspects (EBA) Screen

differs significantly from the CUTOFFS screen or the EBA screen. The user may graphically move upper and lower cutoffs against the context of actual options to be included or excluded, rather than merely against an abstract numerical scale.

4.3.3.2 Justify (partially implemented)--The Justify screen (Figure 11) provides users with a comprehensive evaluative overview of selected options. The objective is to support the final stages of a decision process, in which users seek to examine candidate choices in detail, to look for previously overlooked weak points, and to construct a justification for the choice. The Justify screen for a given option displays the score of that option on each attribute, the best score of any option on each attribute, and the difference (in standard deviations) between the current option's score and the best score; it also shows how many options scored better than the present one on each attribute and what percentage of the total database they represent. Finally, it indicates if the present option is poor or outstanding on any particular dimension.

A VIEW option is associated with Justify which enables users to "zoom" in on and examine in detail the options which are superior to the given option in any particular dimension.

For some decision makers, the Justify screen might play a central role in decision making. The process of justifying a choice may lead to reconsideration and revision of previous preference judgments. Montgomery (1983) has argued that decision making in general is a search for good arguments or justifications. A characteristic strategy is to accept an option as justified only if efforts to create a *dominance* structure for that option are successful, i.e., when preferences can plausibly be represented in such a way that the option appears as good or better than other options on all dimensions. A stronger justification occurs when the preferred option is shown to be uniquely outstanding on at least one dimension. The Justify screen enables users to ascertain quickly whether requirements of this sort are satisfied. If not, users may alter the

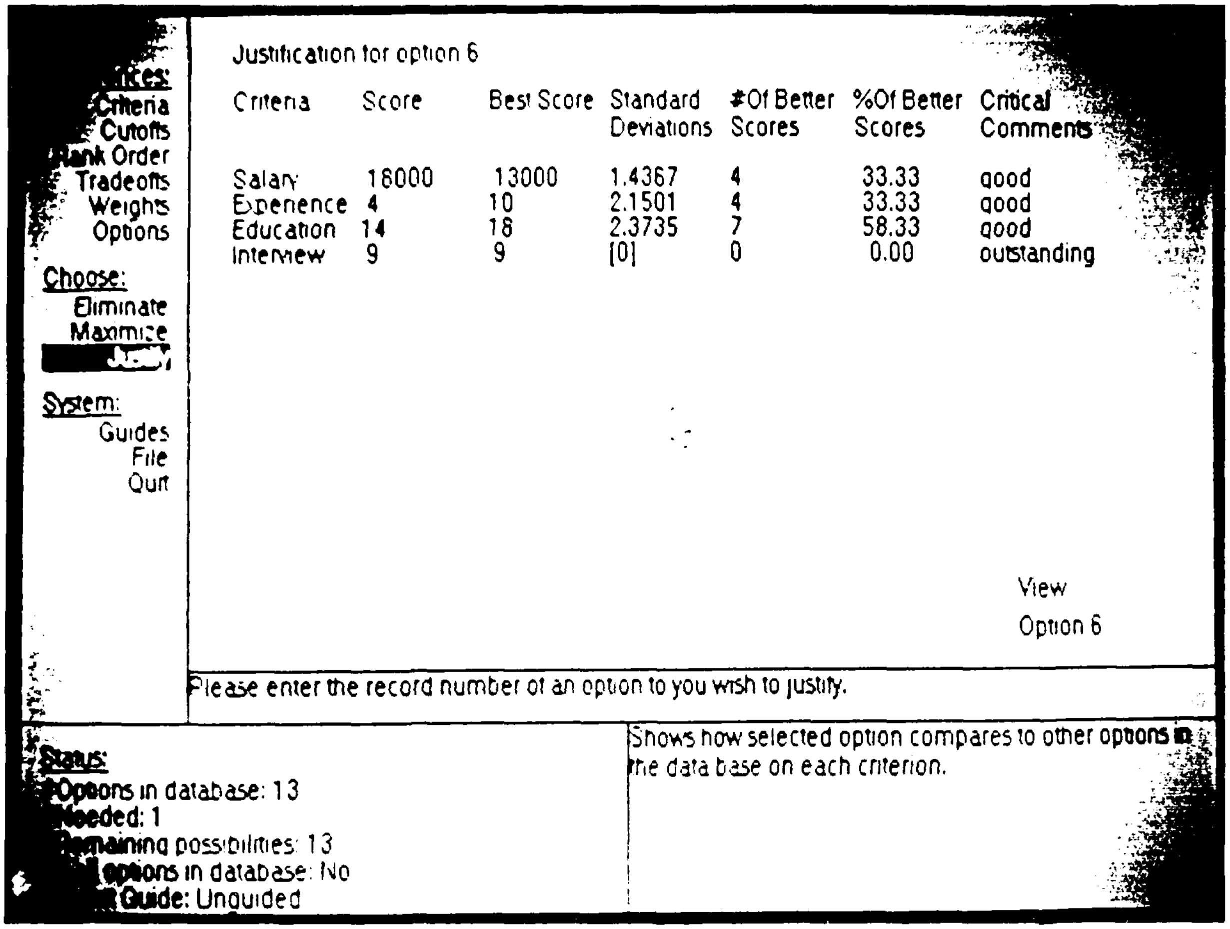


Figure 11: Justify Screen

representation of their preference model until dominance applies, e.g., by combining attributes (via the problem structuring screen), by reducing the importance of attributes on which the preferred option is poor, or by reconsidering the assessment of the performance of one or more options on an attribute.

Advisory prompts will notify users when an option is itself dominated, or is especially poor in some dimension. In addition, the system will track user efforts to establish a dominance structure, and prompt when alterations in previous preferences are excessive according to a user-set criterion.

4.3.3.3 Focus (planned)--Traditional multiattribute utility analysis requires precise numerical assessments of the relative importance of all evaluative dimensions. Both ELIMINATE and JUSTIFY simplify the choice process by enabling the user to employ simple non-compensatory judgments, i.e., comparisons *within* (rather than across) attributes. An ordering of attributes by importance is the only across-attribute information required. The result is a selection of options that may, on occasion, overlook important tradeoffs. Advisory prompts are provided to protect against this. An alternative strategy for simplifying choice, however, is to retain the goal of selecting alternatives with the highest expected utility (i.e., the highest overall score allowing for tradeoffs), but to elicit compensatory assessments from users only to the degree *required* by the particular choice problem at hand.

The FOCUS guide steps the user through the minimal set of assessments required to narrow the option set to the number desired. FOCUS begins with the weakest possible test, dominance, to determine if that is sufficient to obtain the needed weeding out. Only if this fails does it step progressively through queries for stronger and stronger inputs from the user. In all cases, it seeks out aspects of preference knowledge that are likely to have the greatest impact on narrowing down the option set (e.g., the order of importance of attribute A and B; whether C is at least twice as important as D; etc.). As a result, the user's choice problem may be solved with the least judgment effort from the user.

In addition, at any point, the user has the option of short-circuiting this process by instructing the system to "extrapolate" a set of constraints that *would* solve the problem. The system then selects a set of weights consistent with the information thus far provided by the user, and ranks the alternatives with respect to those weights. A sensitivity analysis is also displayed, to permit the user to assess how sensitive the ranking is to the set of weights chosen. If he desires, the user may then provide additional judgments of his own to "correct" the system's extrapolation.

4.4 Implementation

This section provides a summary of the hardware and software approach.

4.4.1 Hardware. An IBM AT system was used for development of the aid. Software produced operates on both PC- and AT-compatible machines. These are both 16-bit microprocessors, the PC having an 8-bit data path provided by the Intel 8088 processor, and the AT having a 16-bit data path due to its Intel 80286 processor. For development purposes, machines have been equipped with floating point co-processors (8087/80287) to improve computational speed, hard disks, and at least 512KB of random access memory. The developed software does not require the co-processors (but will utilize them when available) and requires no more than 256KB of memory (the minimum available on the PC or AT).

The aiding system, like the submarine approach/attack planning aid developed under Phase I of this project, utilizes interactive graphics heavily. We anticipate that the present low-resolution (320 x 200 pixels with 4 simultaneous colors) video systems used by personal computer owners will be largely replaced within the next two to three years with higher resolution systems. For this reason, we are utilizing the recently available IBM Enhanced Graphics Adapter (640 x 350 pixels with 16 simultaneous colors) and an RGB color monitor of no less than 640 x 350 pixel resolution.

4.4.2 Software Software consists of the following:

- A set of software modules written in C and comprising the user-system interface. These provide the user link to the various personalizing modules (Select, Planning, Adjust, Alert, Advisory).

- A Data or Knowledge module consists of two components: (1) a processing subsystem written in C containing the rules appropriate to support evaluations based on a variety of techniques, ranging from elimination by aspects to multiattribute utility analysis; (2) a database management subsystem, written in C and utilizing in addition components of an existing system, dBASE III.

- A graphics interface module. Because of the current lack of standards for graphics software and the variety of graphics hardware which must be supported if reasonable market penetration is to be achieved, all graphics functions are performed by a distinct software module. This will make future modifications relatively simple. This is written in C, utilizing a graphics system known as "Halo" and developed by Media Cybernetics, Inc. Programming of this system is somewhat similar to programming of the Virtual Device Interface (VDI) graphics system being released very shortly by IBM. The VDI approach offers the capability of automatically utilizing whatever resolution is available on a (VDI-supported) device.

5.0 EXPERIMENTAL RESEARCH ON INDIVIDUAL DIFFERENCES IN DECISION STRATEGIES

5.1 Method

A personalized decision aid may serve as a productive testbed for exploration of hypotheses regarding individual difference in preferred decision making strategies. A full exploration of this potential was not possible within the resource constraints of the present project; however, a very preliminary study was conducted in order to: a) test the viability of hypotheses underlying personalized and prescriptive decision aiding techniques, b) illustrate the use of the prototype system as an experimental testbed.

The following research questions were addressed:

- Do people in fact use different problem solving approaches?
- Is an aid which adapts to user differences preferable to an inflexible aid?
- Do different tasks induce different problem solving approaches?
- Do different cognitive styles of users induce different problem solving approaches?

These questions were addressed by: a) providing a flexible condition in which subjects could select their own decision-making strategy utilizing the prototype aid; b) comparing conditions in which users could flexibly select their own decision-making strategy with conditions in which a particular strategy was imposed upon them; c) providing tasks which differed in the degree and nature of the uncertainty about values; d) comparing users who were self-described analytics with users who were self-described intuitives.

The study employed by a 3 x 4 x 3 design with two within-subjects factors: task type and decision strategy, and one between-subjects factor: cognitive style. Each subject played the role of a personnel director of a large corporation. The subject was presented with twelve written scenarios. In each scenario, the subject had to hire three people out of twenty candidates for a particular job.

Task types varied as follows:

- Uncertainty: Subjects were provided a description of job requirements, which was mis-matched with information about candidates provided on their resumes.

- Certainty: Subjects were given descriptions of the preferences of the relevant department head in a form which matched information provided on the resumes.

- Conflict: Subjects were given descriptions of the preferences of two relevant department heads, each of whom might make use of the new employee, in a way which matched resume information; the preferences of the two department heads were inconsistent with each other.

The decision strategy condition was either flexible or inflexible. If inflexible, subjects were told which of three different decision strategies to use in each scenario. The possible strategies were:

- Eliminate: Assess cutoffs (or minimum requirements) on each dimension.

- Weights: Assess the relative importance of different dimensions.

- Tradeoffs: Assess ranges of possible relevant importance of dimensions.

In the flexible condition, subjects were able to choose for themselves which of these strategies they would use in each scenario.
In addition, subjects were asked to provide ratings of their own approach to problem-solving on two scales: one reflecting their degree of intuitiveness, and the other reflecting their degree of analyticality. All subjects fell into one of three groups: those who rated themselves high (greater than 4 on a 7-point scale) on intuitiveness, but not on analyticality, those who rated themselves high on analyticality, but not on intuitiveness, and those who rated themselves high on both dimensions.

For each problem, the time required to solve the problem, the subject's subjective confidence in the solution, and the subject's subjective satisfaction with the system on that problem, were recorded. In addition, in the flexible conditions, the subject's choice of decision strategy was recorded. Also, a process trace of each subject's use of the system has been stored.

Predicted impact of task conditions on decision strategies. In the uncertainty condition, the department heads' preferences in terms of hiring are not stated in terms of the attributes which are provided in the resumes. The user must bridge this gap, i.e., he must predict or infer the causal impact of traits described in the resume on achievement of the department head's goals. For example, if the department head's preferences include that the new employee write well and work well with numbers, then the subject might infer that a high score on the education test, as described in the resume, will be correlated with the achievement of those goals. Similarly, if the department head's preferences include handling unexpected situations or crises, then the subject might predict that a job candidate with many years experience would do well on those objectives. This type of causal modeling, rudimentary though it is, is not very well supported by decision strategies that require judgments of the relative importance of different dimensions. It is not the relative importance of education, and experience, that most concerns the subject in this condition. It is rather what level of education is required to ensure a high likelihood that the candidate will write well and work well with numbers. Similarly, the subject would be concerned with what level of experience is required to ensure a high likelihood that the candidate will handle unexpected situations or crises adequately. Assessments of relative importance would divert the subject's attention on the required causal modeling, causally relevant knowledge appears to be represented at the level of concrete and [illegible] dimensions, rather than at the more abstract level of "multi attribute utility." In contrast, assessment of goals on individual dimensions fits well with the causal process required in this task. Moreover, assessment of importance weights will be unnecessary, unless all goals cannot be simultaneously achieved. Our hypothesis, then, is that in the uncertainty condition, there will be a greater tendency to use the *eliminate* decision strategy as opposed to either *weights* or *tradeoffs*.

In the conflict condition, subjects are presented with inconsistent sets of objectives, representing the goals of different departments. Their choice must somehow reconcile these. In this condition, it might be difficult for subjects to assess unique cutoffs, or unique importance weights, for each dimension. The tradeoffs strategy, however, enables the subjects to specify ranges of relative importance for the dimensions, thus capturing the ambiguity in preferences of the two department heads. Moreover, the tradeoff strategy lets the subject know immediately how important conflict is; if the total set of job candidates is whittled down to the required three, despite the ambiguity, then there is no need for the subject to invest further effort in resolving the conflict. Our hypothesis in this condition, then, is that the subjects will make greater use of the tradeoff strategy.

In certainty conditions, subjects are given qualitative descriptions of the importance of the objectives in terms which are directly related to the attributes provided in the resumes. It is plausible to suppose that these qualitative descriptions will direct the subject's attention to the relative importance of the objectives. Our hypothesis in this condition then, is that the subjects will make greater use of the weights decision strategy.

Figure 12 summarizes the three hypotheses just described.

5.2 Results

The most fundamental principle of personalized and prescriptive decision aiding is that different decision strategies will be used as a function either of the individual or of the task. This hypothesis was dramatically confirmed. Figure 13 shows that all three strategies were utilized in the course of the study. *Eliminate* and *weights* were used approximately equally often, while *tradeoffs* was utilized somewhat less frequently. A given subject, moreover, did not focus exclusively on a single strategy. As shown in Figure 13, ten of the thirteen subjects utilized two strategies in the course of the study, while only two of the subjects utilized a single strategy throughout.

Do subjects prefer decision aids which adapt to their preferences in decision strategy? The data suggests that they do. Subjects experienced more confidence in solutions, and more satisfaction with the system, with the flexible conditions, as compared with the non-flexible conditions (Figure 14).

It should be pointed out, however, that flexibility comes with a price. Subjects took more time in the flexible conditions, as compared with non-flexible conditions, as shown in Figure 15. Increased time on the problem might be regarded as a potential explanation of greater satisfaction and confidence in the flexible condition. However, it is not the case that subjects experienced greater satisfaction and confidence in general when they spent more time on the problem. Time was inversely correlated with satisfaction and confidence within both flexible and inflexible conditions.

We turn now to the impact of task type and cognitive style on preference and selection of decision strategies. Figure 16 suggests that task type influences the confidence and satisfaction obtained from a given decision strategy, but that the effect is not as clear as predicted in Figure 12. Note first that the certainty condition, as expected, produces more

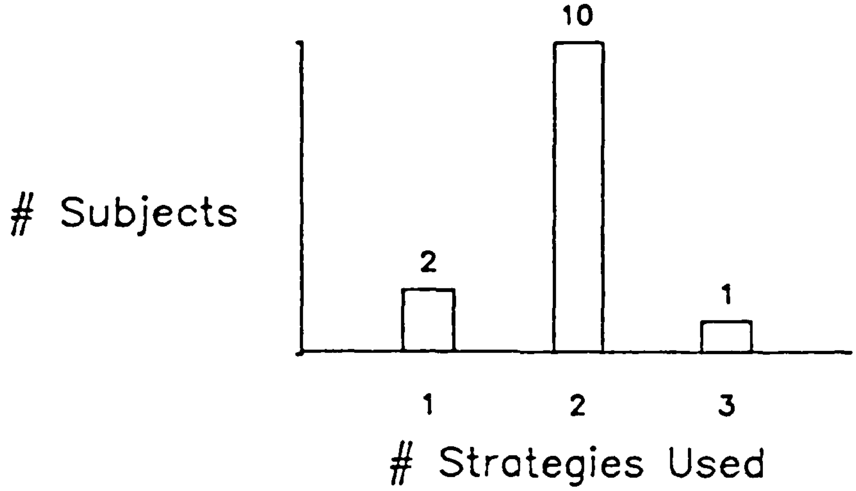
PREDICITIONS

	UNCERT.	CERT.	CONFL.
ELIMINATE	*		
WEIGHTS		*	
TRADEOFFS			*

* = MOST CONFIDENCE
MOST SATISFACTION
CHOSEN IN FLEXIBLE CONDITION

Figure 12: Summary of Hypotheses

IN THE FLEXIBLE CONDITION, ALMOST ALL SUBJECTS USED MORE THAN ONE DECISION STRATEGY



ALL STRATEGIES WERE USED

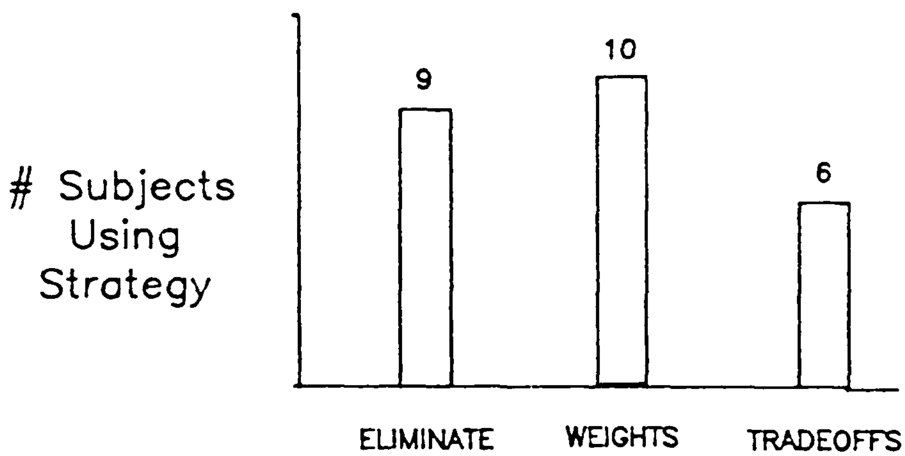


Figure 13: Number of Strategies Used

SUBJECTS EXPERIENCED MORE CONFIDENCE IN SOLUTIONS AND MORE SATISFACTION WITH SYSTEM IN FLEXIBLE VS. NON-FLEXIBLE CONDITION

	CONFIDENCE			SATISFACTION		
	UNCERT.	CERT.	CONFL.	UNCERT.	CERT.	CONFL.
FLEXIBLE	80	85	76	80	86	79
NON-FLEXIBLE	75	83	76	76	82	73

Figure 14: Preferences for Flexible vs. Non-Flexible Conditions

BUT SUBJECTS TOOK MORE TIME IN FLEXIBLE THAN NON-FLEXIBLE CONDITIONS

MINUTES	UNCERT.	CERT.	CONFL.
FLEXIBLE	16.22	12.17	15.53
NON-FLEXIBLE	11.46	10.87	13.31

NOTE: TIME WAS INVERSELY CORRELATED WITH SATISFACTION AND CONFIDENCE, WITHIN BOTH FLEXIBLE AND NON-FLEXIBLE CONDITIONS (ONE EXCEPTION: NON-FLEXIBLE/TRADEOFFS). (SO TIME DIFFERENCE DOES NOT ACCOUNT FOR DIFFERENCE IN SATISFACTION AND CONFIDENCE BETWEEN FLEXIBLE AND NON-FLEXIBLE CONDITIONS.)

Figure 15: Solution Time Under Flexible vs. Non-Flexible Conditions

CONFIDENCE IN SOLUTIONS AND SATISFACTION WITH SYSTEM TENDED TO VARY WITH DECISION STRATEGY (FOR A GIVEN PROBLEM TYPE)

NON-FLEXIBLE	CONFIDENCE			SATISFACTION		
	UNCERT.	CERT.	CONFL.	UNCERT.	CERT.	CONFL.
ELIMINATE	77 *	86	74	77 *	84	72
WEIGHTS	77	86 *	74	82	85 *	72
TRADEOFFS	70	78	78 *	68	78	74 *

* = STRATEGY PREDICTED BEST FOR A GIVEN PROBLEM TYPE

COMPARING PREDICTED BEST WITH OTHER STRATEGIES:

NON-FLEXIBLE	CONFIDENCE	SATISFACTION
PREDICTED	80	79
NON-PREDICTED	77	76

NOTE: ELIMINATE AND WEIGHTS WERE APROXIMATELY EQUAL ACROSS ALL PROBLEM TYPES.

Figure 16: Confidence and Satisfaction as a Function of Task Type and Strategy

confidence and satisfaction than either the uncertainty or the conflict conditions, regardless of the decision strategy that is used. There is however, no pronounced advantage of any one decision strategy across all task types. Rather, *eliminate* and *weights* strategies appear to have an advantage in the uncertainty and certainty conditions, while *tradeoffs* has an advantage in the conflict condition. Thus it appears that some of the subjects were utilizing the tradeoffs strategy in the predicted manner: i.e., to represent the ambiguity in preference caused by the conflict of the two department heads. The results also suggest that the *tradeoffs* strategy was especially bad in the uncertainty condition. This is consistent with our prediction that the uncertainty condition requires causal modeling which clashes with the requirement to carefully assess relative importance. The *tradeoffs* strategy requires a great deal more effort and more assessments of relative importance than the *weights* strategy. Contrary to the prediction, however, there was no advantage of *eliminate* over *weights* in the uncertainty condition. There was no clear pattern of effects of task type on the choice of decision strategy in the flexible condition.

In contrast to task type, there was a clear-cut influence of user cognitive style on the choice of a decision strategy in the flexible condition. As shown in Figure 17, the *eliminate* strategy was chosen far more frequently than the other strategies by self-described intuitive subjects. The *tradeoffs* strategy was more frequently chosen by self-described analytic subjects. (It is of incidental interest to notice that subjects who described themselves both as intuitive and analytic had a pattern of preference more closely matching that of the intuitive subjects.) These results are compatible with the idea that reasoning concretely in terms of specific goals on individual dimensions corresponds to an intuitive cognitive style, while comparing the relative importance of different dimensions corresponds to an analytic, or more abstract cognitive style.

CHOICE OF STRATEGY IN FLEXIBLE CONDITION WAS HEAVILY INFLUENCED BY WHETHER SUBJECT WAS INTUITIVE OR ANALYTIC.

# PROBLEMS	INTUITIVE	ANALYTIC	EQUAL
ELIMINATE	9	2	7
WEIGHTS	5	4	3
TRADEOFFS	1	6	2
	n=5	n=4	n=4

ELIMINATE WAS FAVORED BY INTUITIVE SUBJECTS

TRADEOFFS WAS FAVORED BY ANALYTIC SUBJECTS

Figure 17: Effect of Cognitive Style on Strategy Selected

5.3 Conclusions

These results can, at best, be regarded as highly preliminary and tentative. However, certain results stand out clearly and deserve further exploration. First, individual decision makers differ both among themselves and from task to task in the decision strategy which they prefer. Second, a personalized aid which facilitates different approaches to solving problems leads to greater confidence and more satisfaction with the system. Third, it may be possible to predict user preferences among decision strategies by user self-assessments of cognitive style. Finally, and perhaps most importantly, the data suggests that the decision strategy options offered to users by this aid are meaningful ones, and that this system may have considerable utility as an experimental testbed for additional research.

6.0 CONCLUSION

The work reported here has demonstrated that principles of personalized and prescriptive decision aiding, originally developed in the context of submarine command and control, can be generalized successfully to a quite different decision making context. Submarine attack planning and personnel evaluation differ in degree of time stress, in the relative importance of inference and choice, in the availability of objective measures of success, in the organizational role of the aid and the user, and in numerous other ways. Yet each of these contexts poses a similar requirement for decision support that is tailored to individual styles of problem solving and decision making and which provides, at the same time, prescriptive guidance and advice. A common set of cognitive interface modules has been found to satisfy this need in each case.

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